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# An Evaluation of the International Maritime Organization's Gaseous Agents Test Protocol


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16. Abstract

This report provides an evaluation of three gaseous halon alternatives (CEA-410, FM-200, and NAF S-III) and one gas/powder mix (Envirogel) in full-scale machinery space applications. Halon 1301 was also tested to serve as a baseline comparison. The primary objective of this investigation was to evaluate the International Maritime Organization's draft test protocol for gaseous halon alternative fire extinguishing systems. The evaluation focused on various aspects of the test protocol such as compartment configuration, fire scenarios, discharge system parameters, and decomposition product formation.

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# METRIC CONVERSION FACTORS

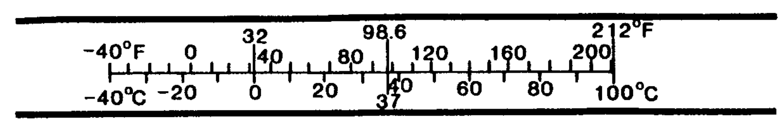
## Approximate Conversions to Metric Measures

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| in | inches | *2.5 | centimeters | cm |
| ft | feet | 30 | centimeters | cm |
| yd | yards | 0.9 | meters | m |
| mi | miles | 1.6 | kilometers | km |
| | | **AREA** | | |
| $in^2$ | square inches | 6.5 | square centimeters | $cm^2$ |
| $ft^2$ | square feet | 0.09 | square meters | $m^2$ |
| $yd^2$ | square yards | 0.8 | square meters | $m^2$ |
| $mi^2$ | square miles | 2.6 | square kilometers | $km^2$ |
| | acres | 0.4 | hectares | ha |
| | | **MASS (WEIGHT)** | | |
| oz | ounces | 28 | grams | g |
| lb | pounds | 0.45 | kilograms | kg |
| | short tons (2000 lb) | 0.9 | tonnes | t |
| | | **VOLUME** | | |
| tsp | teaspoons | 5 | milliliters | ml |
| tbsp | tablespoons | 15 | milliliters | ml |
| fl oz | fluid ounces | 30 | milliliters | ml |
| c | cups | 0.24 | liters | l |
| pt | pints | 0.47 | liters | l |
| qt | quarts | 0.95 | liters | l |
| gal | gallons | 3.8 | liters | l |
| $ft^3$ | cubic feet | 0.03 | cubic meters | $m^3$ |
| $yd^3$ | cubic yards | 0.76 | cubic meters | $m^3$ |
| | | **TEMPERATURE (EXACT)** | | |
| °F | Fahrenheit temperature | 5/9 (after subtracting 32) | Celsius temperature | °C |

*1 in = 2.54 (exactly).


## Approximate Conversions from Metric Measures

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| mm | millimeters | 0.04 | inches | in |
| cm | centimeters | 0.4 | inches | in |
| m | meters | 3.3 | feet | ft |
| m | meters | 1.1 | yards | yd |
| km | kilometers | 0.6 | miles | mi |
| | | **AREA** | | |
| $cm^2$ | square centimeters | 0.16 | square inches | $in^2$ |
| $m^2$ | square meters | 1.2 | square yards | $yd^2$ |
| $km^2$ | square kilometers | 0.4 | square miles | $mi^2$ |
| ha | hectares (10,000 $m^2$) | 2.5 | acres | |
| | | **MASS (WEIGHT)** | | |
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.2 | pounds | lb |
| t | tonnes (1000 kg) | 1.1 | short tons | |
| | | **VOLUME** | | |
| ml | milliliters | 0.03 | fluid ounces | fl oz |
| l | liters | 0.125 | cups | c |
| l | liters | 2.1 | pints | pt |
| l | liters | 1.06 | quarts | qt |
| l | liters | 0.26 | gallons | gal |
| $m^3$ | cubic meters | 35 | cubic feet | $ft^3$ |
| $m^3$ | cubic meters | 1.3 | cubic yards | $yd^3$ |
| | | **TEMPERATURE (EXACT)** | | |
| °C | Celsius temperature | 9/5 (then add 32) | Fahrenheit temperature | °F |



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**Executive Summary**

1. Purpose of Report

The results of the full-scale fire testing evaluation of the International Maritime Organization's (IMO) draft test protocol for alternative gaseous agents for machinery spaces and cargo pump rooms are presented. These experiments were conducted by the United States Coast Guard Research & Development Center (R&D Center). The purpose of the evaluation was to establish the effectiveness and equivalency of the untested protocol to the current level of protection provided by regulation. The testing resulted in a finding that the proposed protocol provides a reasonable basis for evaluating gaseous agent systems. The report makes recommendations for areas where the draft protocol needs improvement.

2. Background

The production of the fire suppressant gas, Halon 1301, was banned by the international treaty, the Montreal Protocol. This has effectively eliminated one of the two primary fire suppressant gases used for shipboard fire protection. To address this situation the IMO drafted a test protocol for alternative gaseous agents for machinery spaces and cargo pump rooms for possible inclusion in its Safety of Life at Sea (SOLAS) regulations. This protocol, Draft Test Method for Fire Testing of Fixed Gas Fire Extinguishing Systems as referred to for Machinery Spaces and Cargo Pump Rooms under SOLAS 74, was drafted at the 40th meeting of the Maritime Safety Committee's Fire Protection (FP) subcommittee. The United States Coast Guard, as a member of the committee and its subcommittees, evaluated this untested protocol before accepting its incorporation into SOLAS.

The Marine Safety and Environmental Protection (G-M) organization's Life Saving and Fire Safety Division (G-MSE-4) requested that the Coast Guard Research & Development Program conduct an evaluation of this important test protocol. Due to the limited time before the next meeting of the Fire Protection subcommittee, the R&D program incorporated the evaluation

into its ongoing fire research project which is looking into equivalencies of other fire suppressant systems for machinery spaces.

3. Results and Conclusions

The testing was conducted at the U.S. Coast Guard's Fire & Safety Test Detachment in Mobile, AL. A test compartment was constructed onboard the test vessel STATE OF MAINE that met the requirements in the draft protocol. To ensure testing actual commercial systems while keeping within budget restraints, the Coast Guard entered into four Cooperative Research and Development Agreements with industry. These provided the Coast Guard with actual commercial systems and agents for testing, and provided valuable performance information to the industry participants.

The tests were conducted over a six-week period in June and July of 1996. Three gaseous alternative agents, one gas/powder mix, and baseline Halon 1301, were tested against the protocol. The three gaseous agents were capable of meeting all of the protocol's performance criteria. The gas/powder mix was only run against two of the four test scenarios due to poor performance related to distribution system problems. Those tests did, however, identify that the protocol as drafted, might not be as appropriate for hybrid agents such as this gas/powder mix.

Freeburn tests of the fires only identified that fire sizes were too large for the longer discharge time the protocol allows for inert gas agents. The large fires would self extinguish due to oxygen depletion halfway through the allowed discharge time. It was also determined that the re-ignition scenario in the protocol was inadequate to evaluate an agent's protection against re-ignition. This was due to the hot surface not retaining sufficient energy to cause re-ignition. This report also identifies other areas that would benefit from further study. Examples of these are bulkhead mounted nozzles and tests with storage cylinders at their lowest allowable operating temperature.

4. Recommendations

Recommendations on four limitations of the protocol as originally drafted are included in the report. They are as follows:

a. The protocol should only apply to total flooding gases and should not be used as the only basis of evaluating agents containing solid or liquid aerosols.

b. The procedure requires modification if it is to be used with systems that have discharge times greater than 15 seconds. This can be accomplished with smaller fires and subsequent reduced oxygen depletion.

c. The average nozzle pressure, maximum discharge time, and maximum nozzle spacing used in the telltale fire tests should form the design limits used in installations.

d. Since there is no long duration re-ignition test or hot surfaces which retain sufficient energy to form a long duration ignition source, a minimum acceptable agent hold time should be required in the design and installation standard.

Additional areas of the draft protocol that would benefit from further study are also identified in the report.

## 1.0 INTRODUCTION

This report gives an evaluation of the draft International Maritime Organization's (IMO) gaseous agent fire test protocol [1]. The protocol, modified as a result of this testing, was approved by the IMO's Maritime Safety Committee on December 12, 1996, published as MSC Circular 776 [], and is expected to be used throughout the world for the evaluation of halon alternative gases. The development and approval of MSC Circular 776 was directly related to the U.S. Coast Guard test program described in this report and related U.S. involvement at IMO.

At the time the U.S. Coast Guard's halon alternative Research and Development test program was conducted, the IMO test protocol was in a draft stage. Although there were changes between the draft test protocol and the final approved protocol, none of the changes were substantive. Therefore the results of this report generally apply to both the draft test protocol that was being considered at IMO in September 1996 and the final protocol that was approved in December 1996.

The U.S. Coast Guard is interested in the development of alternatives to halon fire extinguishing systems for use on commercial vessels because the U.S. Coast Guard is responsible for ensuring that the public and the commercial marine industry are adequately safeguarded from fire. Gaseous halon alternatives have increasingly been proposed for use for extinguishing fires in machinery spaces and other hazards aboard commercial vessels. The U.S. Coast Guard sought to find and implement a standardized means for evaluating the firefighting capabilities of halon alternatives that was comprehensive, based on science and that could be accepted internationally. International acceptance was necessary because many US users of halon alternatives sail on international voyages and US suppliers sell their systems overseas. The process identified as best meeting this need was the development of testing and use guidelines through the IMO.

During the fortieth meeting of the IMO's Subcommittee on Fire Protection (IMO FP40), a draft test protocol was developed for fixed gaseous halon alternative fire extinguishing systems.

The draft test protocol was developed to establish the extinguishing effectiveness of new gaseous agents and to determine certain design parameters for new systems. The draft test protocol was also intended to establish application limits for new systems to ensure that each new gaseous agent distribution system could achieve an extinguishing concentration at all points in the space being protected. Because the draft test protocol had not been actually tried, it was unknown by the world maritime community whether or not the draft IMO test protocol adequately challenged the effectiveness of new fire extinguishing systems and agents, nor was it known what burdens adoption of the draft tests would place on the industry. The test program described in this report was designed to evaluate and validate (or invalidate) the proposed IMO test protocol so that necessary changes could be identified and incorporated in the final IMO test protocol approved at the Forty First meeting of the IMO Subcommittee on Fire Protection (IMO FP41).

The draft IMO test protocol was evaluated in a purpose built fire test enclosure aboard the U.S. Coast Guard's test vessel STATE OF MAINE. Three gaseous halon alternatives (North American Fire Guardian Technology, Inc.'s (NAFGT) NAF-SIII, 3M Corporation's CEA-410, and Great Lakes Chemical Corporation's FM-200), one gas/powder mix (Powsus Corporation's Envirogel), and Halon 1301 for baseline comparisons were included in this. The U.S. Navy donated the halon 1301 used in the baseline tests. The halon 1301 tests were fundamental to the evaluation of the draft test protocol because they connected the new tests with the performance of halon 1301, an agent that has been widely used in machinery space fires.

In order to meet the schedule, which required completion of all tests prior to IMO FP41, and in order to stay within the allocated budget, the project was structured to allow the participation of industry through formal Cooperative Research and Development Agreements (CRADAs). In general, the CRADAs allowed industry participants, such as agent and equipment manufacturers, the benefit of understanding how their products performed against a draft international test protocol. They were required to furnish and install a fire extinguishing system in accordance with their design within the test compartment. The conduct of all tests was performed by the US Coast Guard with assistance from technical contractors who were under direct US Coast Guard control. For the test program the US Coast Guard provided the test facility, (Fire & Safety Test Detachment , Mobile Alabama, Test Vessel STATE OF MAINE),

facility, (Fire & Safety Test Detachment , Mobile Alabama, Test Vessel STATE OF MAINE), test compartments, all fuels, instrumentation, test personnel, transportation to the test vessel, and the final report.

This test program was the first ever use of CRADA authority by the US Coast Guard. The USCG R&D Center established CRADA authority and signed agreements with industry in time to complete the test series prior to the IMO fire Protection Meeting.

CRADAs were established with the following companies:

- Ansul Inc. Marine Division using North American Fire Guardian Technology, Inc.'s (NAFGT) agent NAF-SIII;

- 3M, Minnesota Mining and Manufacturing using CEA-410 and a distribution system provided by Thorne Securities, Inc.;

- Kidde-Fenwal Inc. using Great Lakes Chemical Corporation's agent FM-200; and

- Powus, Inc. using Envirogel using a generic distribution system.

The results of this test program were presented to the Working Group on Firefighting Systems at IMO at FP41. The outcome of IMO FP41 was a final set of use guidelines for halon alternative gases. The guidelines and test protocol approved at IMO FP41 were forwarded to IMO's Maritime Safety Committee who approved them in December 1996 and published them as MSC Circular 776, given in Appendix [D] of this report.

This report addresses the tests conducted in accordance with the approved test plan [2].

## 2.0 OBJECTIVES

The objective of this test program was to evaluate the IMO's draft test protocol for gaseous halon alternative fire extinguishing systems. The evaluation focused on various aspects of the test protocol such as compartment configuration, fire scenarios, discharge system parameters, and decomposition product formation. Fire aspects included fire size, fire location, and fuel type. Discharge system parameters included design concentration, discharge time, nozzle type, and nozzle location.

## 3.0 EXTINGUISHING AGENTS

Five agents were included in this evaluation. These agents include bromotrifluoromethane $CF_3Br$ (Halon 1301), heptafluoropropane $C_3HF_7$ (FM-200), perfluorobutane $C_4F_{10}$ (CEA-410), a hydrochlorofluorocarbon blend (NAF-HCFC Blend A), and an ammonium polyphosphate HFC mixture referred to as Envirogel. Envirogel was tested with two different HFCs, HFC-125 and HFC-134A. FM-200 is manufactured by Great Lakes Chemical Corporation, CEA-410 by 3M Corporation, NAF-SIII by NAFGT, and Envirogel by Powsus. The physical/chemical characteristics of the five agents are listed in Table 1. Also included in Table 1 are the agents' cup burner extinguishment concentrations for n-heptane [3]. The table also includes the gas concentrations used in the telltale test (Fire Scenario 1) and subsequent large fire tests (Fire Scenarios 2-4) as per the IMO test requirements.

## Table 1. Extinguishing Agents – Chemical and Physical Properties

| | Halon 1301 | CEA-410 | FM-200 | NAF-SIII | Envirogel | |
|---|---|---|---|---|---|---|
| Chemical Formula | $CF_3Br$ | $C_4F_{10}$ | $C_3HF_7$ | HCFC Blend | $C_2HF_5$* | $C_2H_2F_4$* |
| Molecular Weight | 149 | 238 | 170.03 | 92.9 | 120 | 102 |
| Normal Boiling Point | -57.8°C | -2.2°C | -16.4°C | -38°C | -48°C | -26°C |
| Vapor Pressure, MPa | 1.47 at 21°C | 0.330 at 32°C | 0.405 at 21°C | 0.669 at 21°C | 1.371 at 25°C | 0.668 at 25°C |
| Critical Temperature | 67°C | 113.2°C | 101.7°C | 125°C | 66°C | 101°C |
| Critical Pressure | 3.97 MPA | 2.32 MPA | 2.91 MPA | 6.65 MPA | 3.59 MPA | 4.06 MPA |
| Vapor Density, $kg/m^3$ | 6.26 at 21°C and 0.101 MPA | 9.94 at 25°C and 0.101 MPA | 7.26 at 21°C and 0.101 MPA | 3.84 at 25°C and 0.101 MPA | 5.12 at 21°C and 0.101 MPa | 4.35 at 21°C a 0.101 MPa |
| Liquid Density, $kg/m^2$ | 1567 at 21°C | 1517 at 20°C | 1403 at 21°C | 1200 at 25°C | 1245 at 25°C | 1202 at 25°C |
| n-heptane Cup Burner % Volume Extinguishment | 3.5 | 5.0 | 5.8 | 9.9 | ~10[2] | ~12[2] |
| Telltale Test Concentration (% Volume) | | 5.9 | 6.7 | 10 | 5.0 (160 $g/m^3$)[1] | 5.6 (160 $g/m^3$)[1] |
| Large Fires Test Concentration (% Volume) | 5.0 | 8.2 | 8.7 | 12 | 5.0 (160 $g/m^3$)[1] | 5.6 (160 $g/m^3$)[1] |

Note: * The Envirogel mixture consisted of 40 percent $NH(PO_4)_x$ and 60 percent gaseous agent (HFC-125 or HFC-134A) by weight. The properties listed above pertain to the gaseous agent.

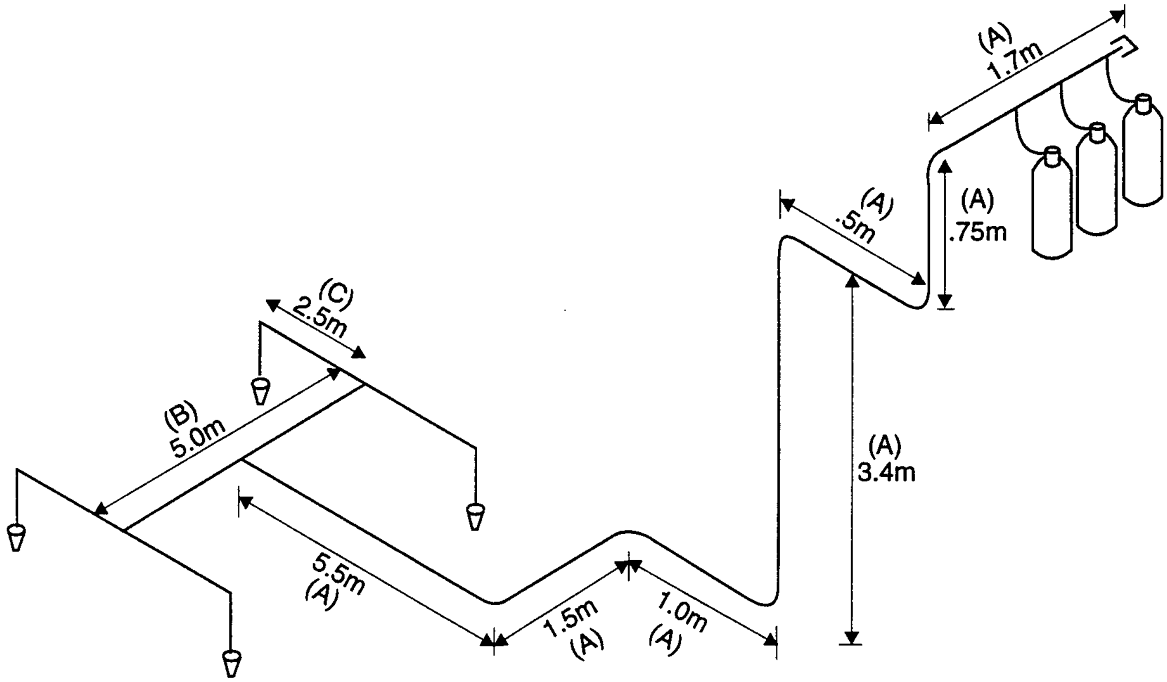
1 Values given are gas concentrations. Parenthetical values are aerosol concentrations.

2 Estimated HFC gas only (no powder).

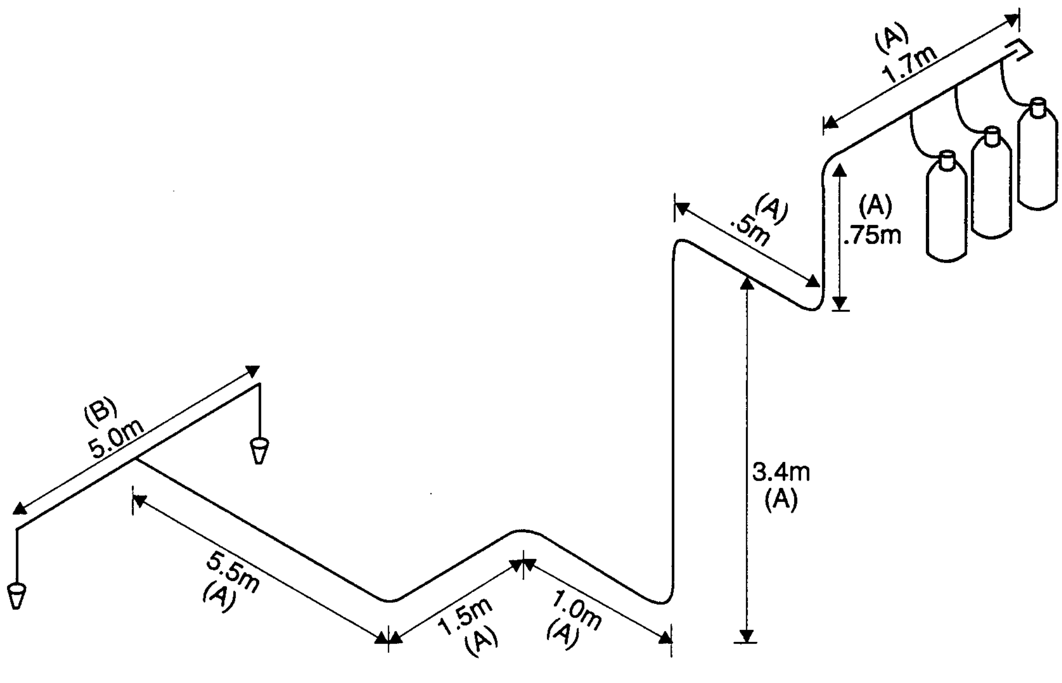
## 4.0 AGENT DISTRIBUTION SYSTEMS

Each agent manufacturer was responsible for the design and installation of its respective distribution system. Each manufacturer was required to submit both a system design and flow/discharge time calculation to the Coast Guard prior to system acceptance. Systems were to be designed for a 10-second discharge time (95% of the mass of the agent in 10 seconds ± 1 second)[1]. Each system consisted of a cylinder bank containing between 1-3 cylinders located on the main deck aft of the test compartment and a two or four nozzle pipe network installed in the overhead of the space. Two generic discharge systems are shown in Figure 1. System design parameters for each manufacturer are listed in Table 2. The amount of extinguishing agent (weight) required to produce the design concentration was determined using the gross volume of the enclosure.

[1] The discharge time is based on 95% of the mass versus reaching the desired concentration as required in other standards, such as in the United States in NFPA 2001 (1996). This difference is not considered significant for most applications. The discharge systems included during this evaluation were similar in design.




FOUR NOZZLE SYSTEM




TWO NOZZLE SYSTEM

Figure 1. — Generic distribution system(s)

**Table 2. Distribution System Parameters**

| Agent | Fire/Test | Conc. (%) | Agent Weight (kg (lb)) | Cylinder Size | No. of Cylinders | Pipe Size (in.) | | | No. of Nozzles | Nozzle Area ($cm^2$ ($in.^2$)) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | A | B | C | | |
| Halon | All | 5.0 | 155 (340) | 600 lb | 1 | 3 | 2 | | 2 | 2.23 (1.12) |
| CEA-410 | Telltales | 5.9 | 312 (686) | 350 lb | 3 | 3 | 2½ | 2 | 4 | 4.65 (0.72) |
| CEA-410 | Large Fires | 8.2 | 444 (977) | 350 lb | 3 | 3 | 2½ | 2½ | 4 | 10.13 (1.57) |
| FM-200 | Telltales | 6.7 | 262 (576) | 350 lb | 2 | 3 | 2½ | 2 | 4 | 7.23 (1.12) |
| FM-200 | Large Fires | 8.7 | 349 (768) | 350 lb | 3 | 3 | 2½ | 2 | 4 | 12.90 (2.0) |
| NAF-SIII | Telltales | 10 | 215 (473) | 600 lb | 1 | 3 | 2 | | 2 | 17.10 (2.65) |
| NAF-SIII | Large Fires | 12 | 264 (580) | 600 lb | 2 | 3 | 2 | | 2 | 21.16 (3.28) |
| Envirogel | All | 4.6/160 $g/m^3$ | 205 (450) | 600 lb | 1 | 3 | 2½ | | 2 | 15.89 (2.46) |

## 5.0 TEST COMPARTMENT

The tests were conducted in a simulated machinery space aboard the test vessel, STATE OF MAINE, at the U.S. Coast Guard Fire and Safety Test Detachment located at Little Sand Island in Mobile, AL. The machinery space was located on the fourth deck of the Number 6 cargo hold. The compartment was constructed to meet the dimensional requirements of the IMO test protocol. The compartment volume was approximately 500 $m^3$ with nominal dimensions of 10 m x 10 m x 5 m as shown in Figure 2. The diesel engine mockup described in the test protocol was located on the fourth deck in the center of the compartment as shown in Figure 3. Air to support combustion was provided naturally through two 2 $m^2$ vent openings located on the fourth deck forward in the compartment. Products of combustion were exhausted from the compartment through a 6 $m^2$ vertical stack located in the back of the compartment (aft). Both the supply vents and vertical stack were closed just prior to agent discharge.

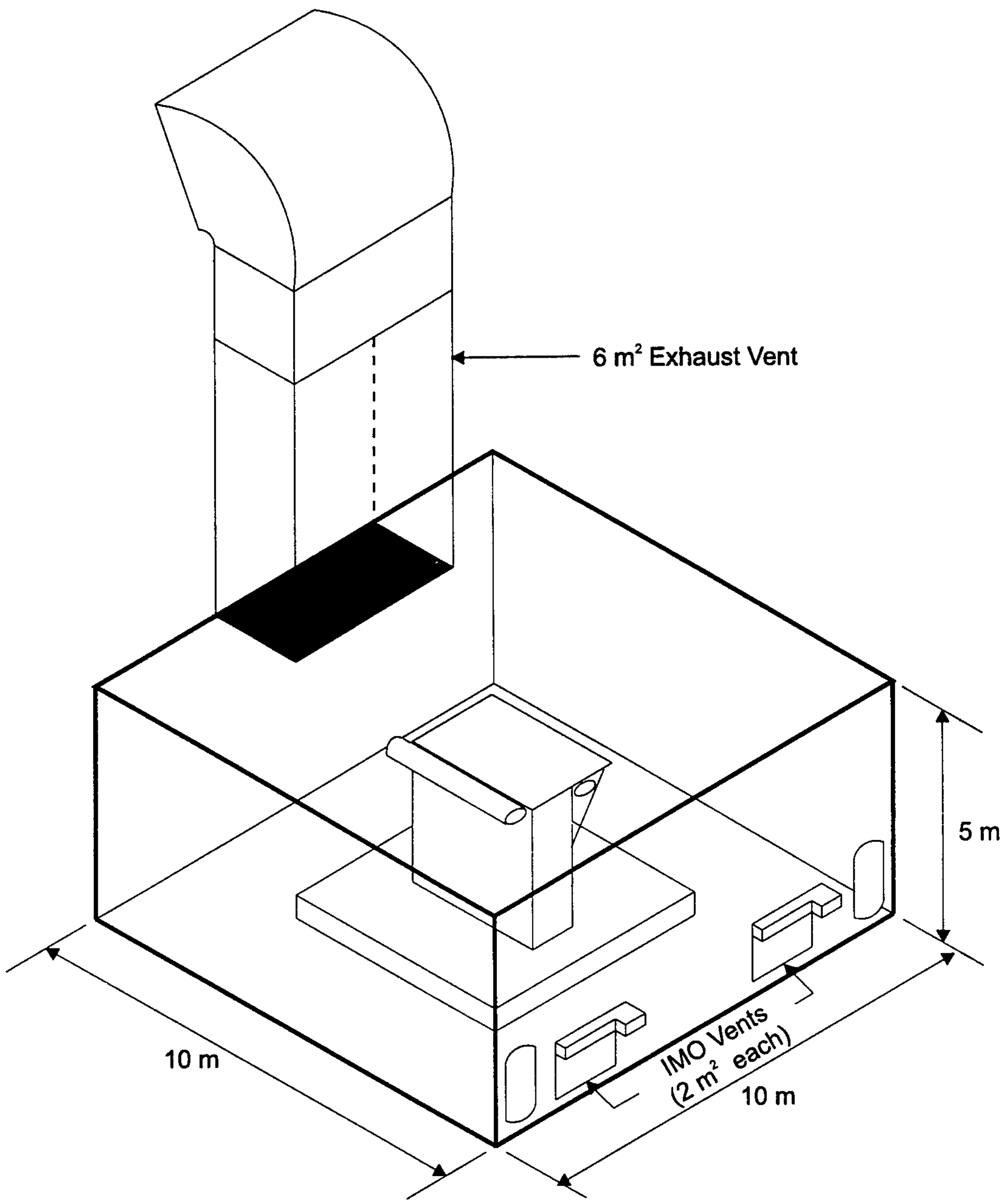
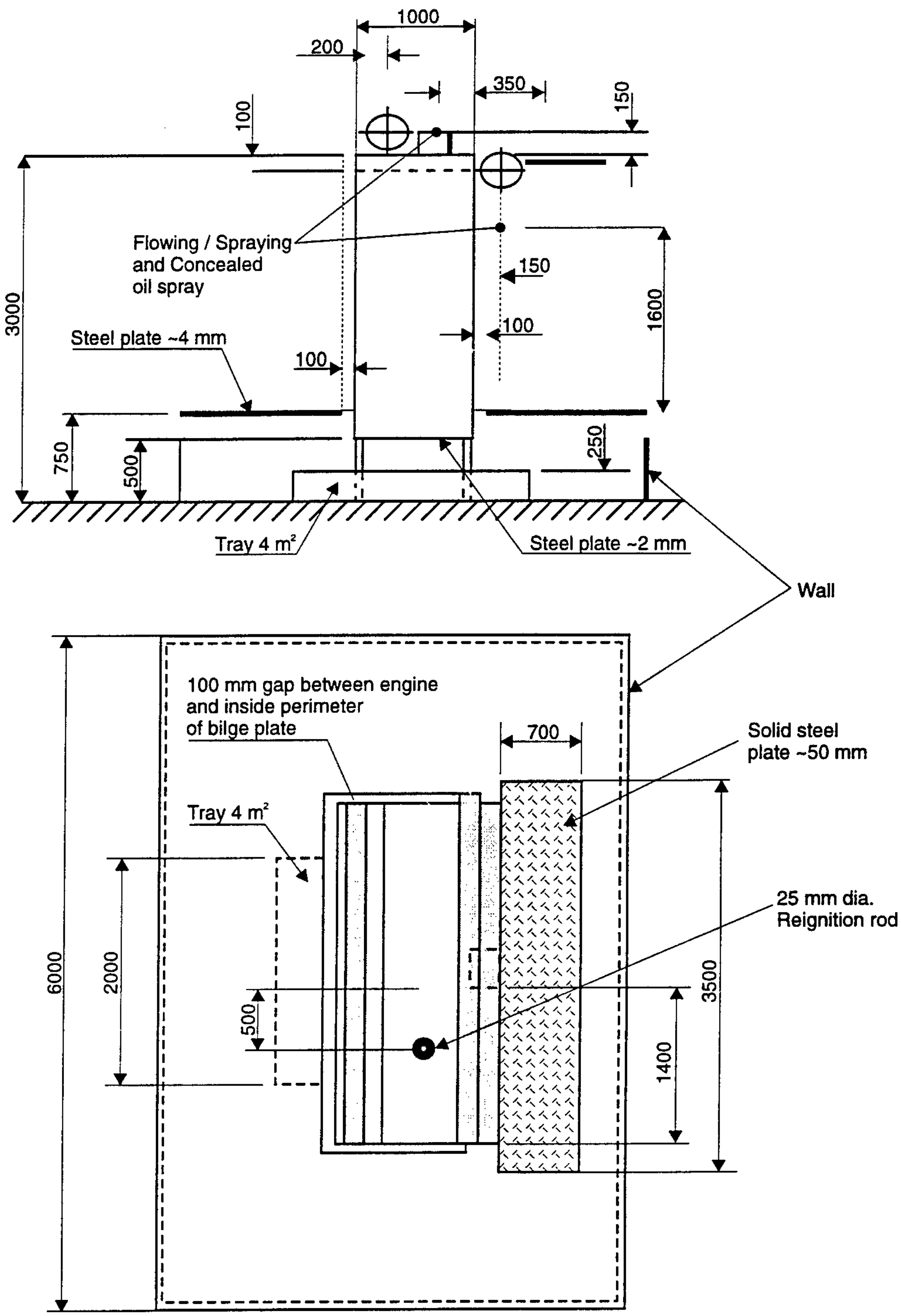



Figure 2 — Machinery space configuration




(All measurements are in mm, unless otherwise noted.)

Figure 3 — Diesel engine mock-up

The enclosure integrity was determined using a door fan test as required in Section 3.2.2 of the test protocol. The door fan test provides information pertaining to the time required for the interface to drop below a specific height or, for the continually mixed case, the agent concentration history. The door fan tests were conducted by Brendle Inc. of Montgomery, AL. Four tests were conducted using air flow rates from 65 to 110 $m^3$/min., which produced compartment pressures ranging from 15 to 40 Pa. Based on the results of these tests, the agent hold times were estimated to be approximately 25 minutes and the equivalent leakage area to be approximately 0.17 $m^2$. The results of the door fan test are found in Appendix B.

## 6.0 FIRE SCENARIOS

The extinguishing agents were evaluated using the four fire scenarios described in the IMO Test Protocol except as noted. The tests required by the test protocol are listed in Table 3 and are designated as Fire Scenarios 1, 2, 3, and 4. Test No. 1 was conducted with 50 mm diameter cans for Fire A verses 100 mm diameter cans. Test No. 3 and 4 were conducted with the 1.25 $m^2$ trays (Fires C and D) were located on the 750 mm high bilge plating adjacent to the mockup verses centered under the mockup. The cold discharge test, not required by the protocol, was abandoned based on the presumption that both the cold discharge test and the telltale fire test provide similar data. The locations of the fires listed in Table 3 are shown in Figure 4.

**Table 3. Fire Scenarios**

| Fire Scenario | Nominal Total Heat Release Rate | Components | Nominal Heat Release Rates | Location (Figure 4) |
|---|---|---|---|---|
| 1 | ~24 kW | 30 $cm^2$ heptane pan fires (telltales) | ~3 kW/ea | Corners (TT |
| 2 | 7.95 MW | Low pressure heptane spray fire (IMO)<br>High pressure diesel spray fire (IMO)<br>0.25 $m^2$ heptane pan fire | 5.8 MW<br>1.8 MW<br>0.35 MW | Top of mockup (S1<br>Top of mockup (S2<br>Side of mockup (P1 |
| 2A | 2.40 MW | Low pressure/flow heptane spray fire #1 (Prop.)<br>High pressure diesel spray fire (IMO)<br>0.25 $m^2$ heptane pan fire | 0.25 MW<br>1.8 MW<br>0.35 MW | Top of mockup (S1<br>Top of mockup (S2<br>Side of mockup (P1 |
| 3 | 4.40 MW | Low pressure/flow heptane spray fire #2 (IMO)<br>Small wood crib<br>2.0 $m^2$ diesel pan fire | 1.10 MW<br>0.30 MW<br>3.00 MW | Side of mockup (S3<br>Deck level (C1<br>Bilge Plate (P2 |
| 3A | 3.40 MW | Low pressure/flow heptane spray fire (Prop.)<br>Small wood crib<br>0.25 $m^2$ heptane pan fire<br>1.25 $m^2$ heptane pan fire | 0.25 MW<br>0.30 MW<br>0.35 MW<br>2.50 MW | Top of mockup (S1<br>Deck level (C1<br>Side of mockup (P1<br>Bilge (P3 |
| 3B | 3.40 MW | Low pressure/flow heptane spray fire (IMO)<br>Small wood crib<br>1.25 $m^2$ diesel pan fire | 1.10 MW<br>0.30 MW<br>2.00 MW | Side of mockup (S3<br>Deck level (C1<br>Bilge plate (P2 |
| 4 | 6.00 MW | 4.0 $m^2$ diesel pan fire | 6.00 MW | Bilge (P4 |
| 4A | 4.75 MW | Low pressure/flow heptane spray fire (Prop.)<br>1.25 $m^2$ diesel pan fire<br>1.25 $m^2$ heptane pan fire | 0.25 MW<br>2.00 MW<br>2.50 MW | Top of mockup (S1<br>Bilge (P5<br>Bilge (P3 |

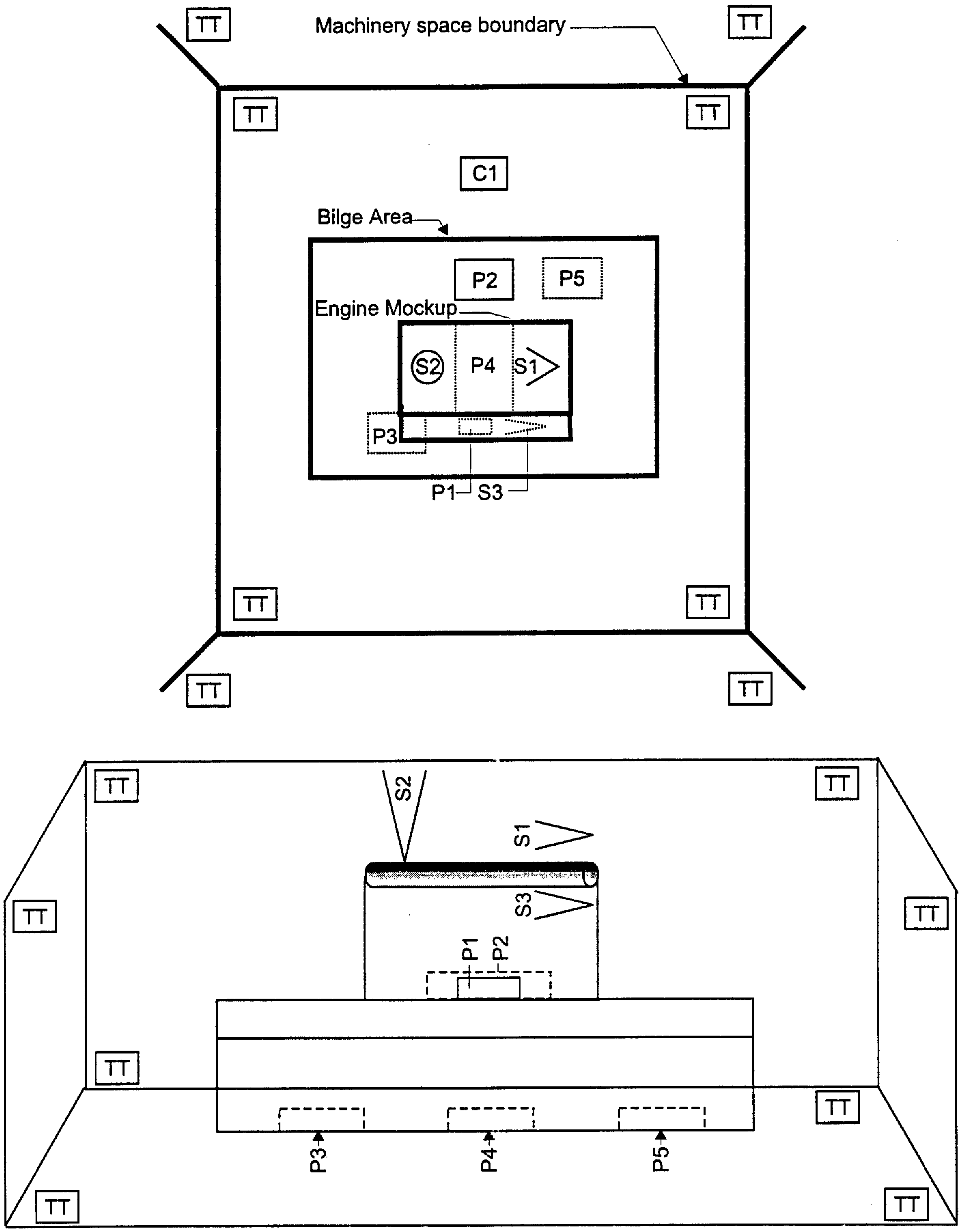



Figure 4 — Fire locations

The United States Coast Guard has recommended that the sizes of the fires be reduced to minimize the effects of oxygen depletion on extinguishment [4]. The proposed recommended fires were also included in this evaluation. These fires are similar in makeup to those described in the test protocol, but have lower heat release rates. These fires are listed in Table 3 and are designated as Fire Scenarios 2A, 3A, and 4A.

An additional fire scenario was also included in this evaluation (Fire Scenario 3B). The 2.0 $m^2$ diesel pan fire described in IMO Fire Scenario 3 was not available for the first agent evaluated and was replaced by a 1.25 $m^2$ diesel pan fire.

Additional information pertaining to the individual spray fires is found in Table 4. The fires were ignited such that the following preburn times occurred before agent discharge (wood cribs - 6:00, pan fires - 2:00, and spray fires - 1:00). Acceptable agent performance was defined as the extinguishment of all hydrocarbon fires in less than 30 seconds of agent discharge. In addition, in Fire Scenario 3, the mass loss of the wood crib must be held to less than 60 percent of its original weight. During Fire Scenarios 3A and 3B, a 30 cm x 30 cm x 30 cm wood crib was substituted for the 45 cm x 45 cm x 20 cm wood crib specified in the test protocol. The cubical crib ignited quicker and sustained burning better than the short flat crib.

**Table 4. Spray Fire Parameters**

| Fire Type | Low Pressure IMO | Low Pressure, Low Flow IMO | High Pressure IMO | Proposed Low Pressure IMO |
|---|---|---|---|---|
| Spray nozzle | Wide spray angle (120-125°) full cone type | Wide spray angle (80°) full cone type | Standard angle (at 6 bar) full cone type | Wide spray angle (120-125°) full cone type |
| Nominal fuel pressure | 8.0 bar | 8.5 bar | 150 bar | 8.5 bar |
| Fuel flow | 0.16 ± 0.01 kg/s | 0.03 ± 0.005 kg/s | 0.050 ± 0.002 kg/s | 0.007 ± 0.0005 kg/s |
| Fuel temperature | 20 ± 5°C | 20 ± 5°C | 20 ± 5°C | 20 ± 5°C |
| Nominal heat release rate | 5.8 ± 0.6 MW | 1.1 ± 0.1 MW | 1.8 ± 0.2 MW | 0.25 ± 0.02 MW |

All fire tests were conducted using the manufacturers' recommended design concentration with the exception of the telltale fire tests. The telltale fires were conducted using the agents' minimum extinguishing concentration, which typically was the cup burner extinguishing concentration for n-heptane or diesel fuel. These concentrations are included in Table 1.

## 7.0 INSTRUMENTATION

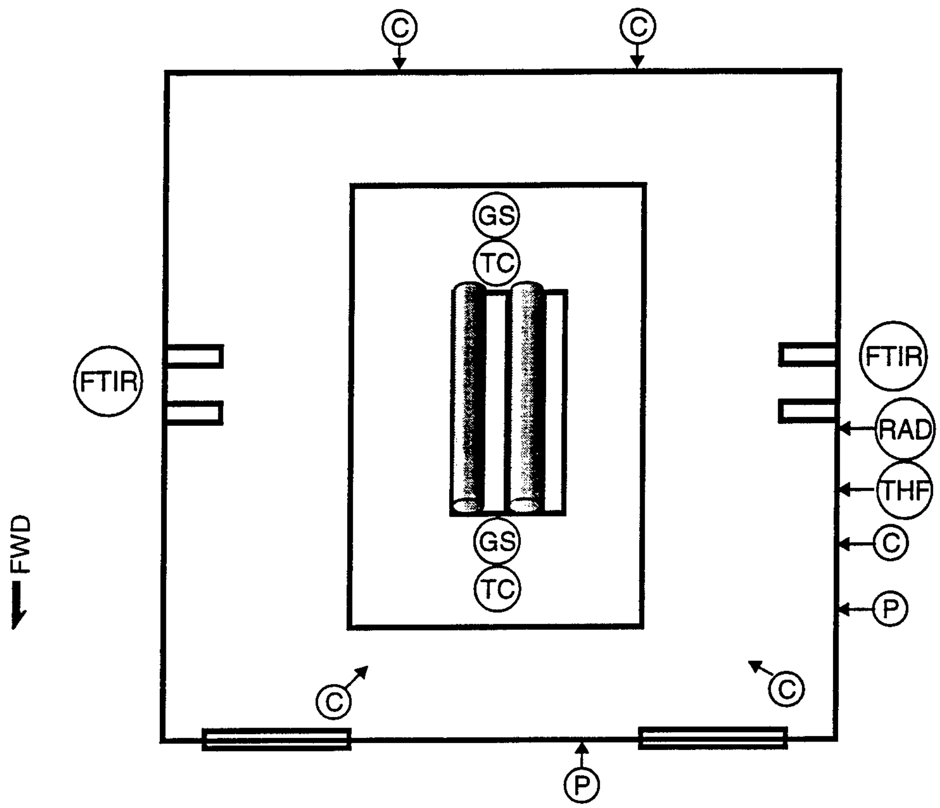
### 7.1 Machinery Space Instrumentation

The machinery space was instrumented to measure both the thermal conditions in the space as well as a wide rage of gas concentrations (agent concentrations, decomposition products, products of combustion, etc.). Instruments were installed to measure air temperatures, fire/flame temperature (to note extinguishment time), radiant and total heat flux, compartment pressure, and $O_2$, $CO_2$ and CO gas concentrations, using the USCG data acquisition system.

The USCG data acquisition system sampled the thermal data at a rate of one scan every six seconds. The instrumentation scheme is shown in Figure 5. A complete list of instruments and instrument location is found in Appendix B. A more detailed description of the instrumentation scheme is listed as follows.

#### 7.1.1 Temperature Measurements

Two thermocouple trees were installed in the compartment. Each tree consisted of eight thermocouples positioned the following heights above the lower deck (1.0, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 4.9 m). Inconel sheathed type K thermocouples (KQIN-18E-600) were used in this application.




| | | |
|---|---|---|
| GS | Gas Sampling $CO$, $CO_2$, $O_2$ | (1.0, 2.5, 4.0 m) |
| TC | Thermocouples | (1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0 m) |
| RAD | Radiometers | (2.0, 4.0 m) |
| THF | Calorimeters | (2.0, 4.0 m) |
| P | Pressure Measurements | (1.5 m) |
| FTIR | FITR Measurements | (1.5 m) |
| C | Video Cameras | |

Figure 5 — Instrumentation

### 7.1.2 Gas Concentration Measurements

Carbon monoxide, carbon dioxide, and oxygen concentrations were sampled at two locations and three elevations in the compartment. These measurements were made at the center line of the space both forward and aft of the engine mockup. Measurements were taken 1.0, 2.5 and 4.0 m above the lower deck.

### 7.1.3 Heat Flux Measurements

Both radiant and total heat flux measurements were recorded at four locations in the compartment. These transducers were installed on the forward and port bulkheads 2.0 and 4.0 m above the lower deck. These instruments were Schmidt Boelter transducers manufactured by Medtherm Co. and had a full-scale range of 0-50 $kW/m^2$. The radiometers were equipped with 150° sapphire windows.

### 7.1.4 Compartment Pressure Measurements

The compartment pressure was measured at two locations in the space (centerline of the forward and port bulkheads 1.0 m above the deck). Setra Model 280E pressure transducers with a range of ±2.48 kPa were used for this application. These instruments have an accuracy of 0.01 percent full scale. Due to the transient nature of the compartment pressures, these transducers were monitored using the high speed, PC-based data acquisition system.

## 7.2 Discharge System Instrumentation

The discharge system was instrumented to provide system pressures, fluid temperatures and pipe wall surface temperatures at various locations throughout the discharge system. These data were collected using a PC-based data acquisition system at a rate of 10 Hz. Compartment pressures were also monitored using this data acquisition system. A description of the discharge system instrumentation is as follows.

### 7.2.1 Pressure Measurements

System pressures were measured at two discharge nozzles, at the center of the pipe network, and on the cylinder discharge manifold. Setra Model 280E pressure transducers were used for this application. These transducers have a range of 0-70 bar with an accuracy of 0.01 percent full scale or 0.007 bar.

### 7.2.2 Temperature Measurements

Fluid temperatures were measured using fast-response, exposed junction, inconel-sheathed, Type K thermocouple probes (Omega KMQIN-062E-300) inserted into the flow (center of the pipe) adjacent to the locations of the pressure measurements. The pipe wall surface temperatures were measured using Type K thermocouples, welded to the pipe surface adjacent to the fluid temperature and system pressure measurement locations.

## 7.3 Agent Concentration and Decomposition Products

Agent concentrations and thermal decomposition products were measured using two KVB/Analect Diamond 20 Fourier Transform Infrared Spectrometers (FTIRs) with calcium fluoride ($CaF_2$) windows. The instruments were installed on the lower level on opposite sides of

the compartment (port and starboard) 1.5 m above the deck. The sample path length for these tests was 0.4 m. Measurements were taken every 15 seconds for the first five minutes of the test and every 60 seconds for the remainder of the test. Due to technical problems, only one set of FTIR measurements were recorded during these tests.

Agent and thermal decomposition product concentrations were determined by comparison with spectra obtained using known concentrations. The specific agent concentrations were determined by the absorbencies at the wave numbers shown in Table 5:

**Table 5. Agent and Decomposition Product Wave Numbers**

| Agent / Compound | Wave length ($cm^{-1}$) |
|---|---|
| Halon 1301 ($CF_3Br$) | 1844 |
| FM-200 ($C_3HF_7$) | 2034 |
| CEA-410 ($C_4F_{10}$) | 1846 |
| NAF-SIII (HCFC Blend A) | 2210 |
| Envirogel (HFC-125) | 2063 |
| Envirogel (HFC-134A) | 2032 |
| Hydrogen Fluoride (HF) | 4003, 4041, and 4077 |
| Hydrogen Chloride (HCl) | 2754, 2781, and 2800 |

The HF concentrations implied by the absorbencies at wave numbers 4003, 4041, and 4077 $cm^{-1}$ were averaged together. HCl concentrations implied by absorbencies at wave numbers 2754, 2781, 2800 $cm^{-1}$ were averaged together.

## 7.4 Fire Instrumentation

Each fire scenario contained specific instrumentation to help note extinguishment and estimate heat release rates. Thermocouples located in the flame region of all fires (telltales included) were used to determine extinguishment times. Fuel system nozzle pressure was used to calculate the fuel flow rates in each test. The energy release rates of the spray fires were calculated using the fuel flow rate and heat combustion of the fuel. This assumes that all of the

fuel is consumed as well as a 100 percent combustion efficiency. The heat release rates of the pan fires were calculated based on the theoretical burning rate of the fuel and the area of the pan.

### 7.5 Video Equipment

Five video cameras were used during each test to visually document the events of the test. Two video cameras were located one on each level inside the compartment. The other three cameras were located outside the compartment primarily viewing the area around the diesel engine mockup. A microphone was also installed in the center of the space to provide the audio for the five video cameras.

## 8.0 PROCEDURES

The tests were initiated from the control room located on the second deck level forward of the test compartment. Prior to the start of the test, the pans were fueled, and the compartment ventilation condition was set. (The two 2 $m^2$ lower vents and the 6 $m^2$ stack vent were opened prior to the start of the test.) The video and data acquisition systems were activated, marking the beginning of the test. One minute after the start of the data acquisition system, the fire ignition sequence was initiated, and the compartment was cleared of test personnel. The fires were allowed to freeburn the specified time before agent discharge (Section 6.0). Ten seconds prior to discharge the vents into the space were closed. The extinguishing system was activated, and the test continued for 15 minutes after discharge at which point the reignition test was conducted where applicable (Fire Scenarios 2, 2A, 3A, and 4A). On completion of the test, the space was ventilated to remove the remaining agent and products of combustion.

## 9.0 RESULTS AND DISCUSSION

### 9.1 Tests Conducted

A total of 46 tests were conducted during this evaluation. These 46 tests are comprised of six freeburn tests, eleven telltale tests, and 29 large fire tests. The discharge nozzles used during these tests are listed in Table 6. The results of the telltale fire tests are shown in Table 7 and the results of the large fire extinguishment tests are listed in Table 8. The freeburn tests were conducted to provide data on the fire environment that would occur in the space in the absence of extinguishing system intervention. The telltale tests were conducted to evaluate the mixing/distribution characteristics of the system/agent and the extinguishment tests were conducted to evaluate the fire extinguishing capabilities of the system/agent. A more detailed description of these tests is given on an agent-by-agent basis in the following sections.

**Table 6. Discharge System Nozzles**

| Nozzle | Manufacturer | Number of Orifices | Radial Pattern | Cone Angle |
|---|---|---|---|---|
| N1 | Ansul | 6 | 360° | 180° |
| N2 | NAFGT | 6 | 360° | 90° |
| N3 | NAFGT | 6 | 360° | 120° |
| N4 | Fenwal | 17 | 360° | 130° |
| N5 | NAFGT | 12 | 360° | 180° and 90° |
| N6 | Thorne | 8 | 360° | 180° |
| N7 | Kidde | 8 | 360° | 165° |
| N8 | Fenwal | 17 | 360° | 130° |
| N9 | Modified Fenwal | 21 | 360° | 180° and 120° |

**Table 7. Telltale Fires – Extinguishment Test Summary**

| Agent | Agent Conc. (%) | Number of Nozzles | Nozzle | Discharge Time (s) | Average Nozzle Pressure (psi) | Extinguishment Results | | | | | | | | Overall Performance |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | High Elevation | | | | Low Elevation | | | | |
| | | | | | | Forward | | Aft | | Forward | | Aft | | |
| | | | | | | Port | Star | Port | Star | Port | Star | Port | Star | |
| NAF-SIII | 10 | 2 | N1 | 11 | 120 | P | P | P | P | P | P | P | P | P |
| NAF-SIII | 10 | 2 | N2 | 10 | 130 | F | F | P | P | P | P | P | P | F |
| NAF-SIII | 10 | 2 | N2 | 11 | 125 | F | P | P | P | P | P | P | P | F |
| NAF-SIII | 10 | 2 | N3 | 11 | 120 | F | P | P | P | P | P | P | P | F |
| NAF-SIII | 10 | 2 | N5 | 10 | 130 | P | P | P | P | P | P | P | P | P |
| CEA-410 | 5.9 | 4 | N6 | 10 | 160 | P | P | P | P | P | P | P | P | P |
| FM-200 | 6.7 | 4 | N7 | 11 | 100 | P | P | P | P | P | P | P | P | P |
| Enviro (134/powder) | 3.6/250 | 2 | N8 | ? | 150 | F | F | F | F | P | P | P | P | F |
| Enviro (134/powder) | 3.6/250 | 2 | N9 | ? | 150 | F | P | P | F | P | F | P | P | F |
| Enviro (134/powder) | 3.6/250 | 2 | N9 | ? | 150 | P | P | P | P | P | P | P | P | P |
| Enviro (125/powder) | 3.0/250 | 2 | N9 | 7 | 150 | P | P | P | P | F | F | P | P | F |

P = pass - fire extinguished in less than 30 seconds.
F = fail - fire not extinguished or extinguished after 30 seconds.
? = Discharge time could not be determined based on discharge system instrumentation.

**Table 8. Large Fire Extinguishment Tests**

| Test | Agent | Agent Concentration (Design) | Number of Nozzles | Nozzle | Discharge Time (s) | Fire Scenario | Extinguishment Time (s) | | | | Agent Concentration (measured) (%) | HF Concentration (measured) (ppm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | 1 | 2 | 3 | 4 | | |
| 12 | NAF-SIII | 12 | 2 | N1 | 9.5 | 2 | 10 | 3 | 3 | N/A | 11.8 | 2500 |
| 13 | NAF-SIII | 12 | 2 | N1 | 9.5 | 3B | 7 | 8 | 14 | N/A | 10.8 | 2300 |
| 14 | NAF-SIII | 12 | 2 | N1 | 9.5 | 4 | 10 | N/A | N/A | N/A | 11.8 | 1000 |
| 15 | Halon | 5 | 2 | N4 | 9.5 | 2 | 15 | 2 | 2 | N/A | 4.6 | 100 |
| 16 | Halon | 5 | 2 | N4 | 9.5 | 3B | 5 | 10 | 11 | N/A | 4.8 | 300 |
| 17 | Halon | 5 | 2 | N4 | 9.0 | 4 | 10 | N/A | N/A | N/A | 4.7 | 400 |
| 19 | NAF-SIII | 12 | 2 | N5 | 9.2 | 2 | 1 | 5 | 5 | N/A | 12.2 | 4400 |
| 20 | NAF-SIII | 12 | 2 | N5 | 9.0 | 3B | 4 | 4 | 4 | N/A | 11.6 | 3400 |
| 21 | NAF-SIII | 12 | 2 | N5 | 9.0 | 4 | 9 | N/A | N/A | N/A | 10.2 | 9000 |
| 22 | NAF-SIII | 12 | 2 | N1 | 10.0 | 2A | 11 | 4 | 4 | N/A | 12.7 | 1600 |
| 23 | NAF-SIII | 12 | 2 | N1 | 10.5 | 3A | 9 | 15 | 12 | 1 | 12.3 | 5100 |
| 24 | NAF-SIII | 12 | 2 | N1 | 10.5 | 4A | 11 | 11 | 2 | N/A | 12.3 | 1900 |
| 26 | CEA-410 | 8.2 | 4 | N6 | 11.0 | 2 | 12 | 2 | 2 | N/A | 7.9 | 2300 |
| 27 | CEA-410 | 8.2 | 4 | N6 | 10.0 | 4 | 12 | N/A | N/A | N/A | 8.7 | 1400 |
| 28 | CEA-410 | 8.2 | 4 | N6 | 10.0 | 3 | 4 | 9 | 9 | N/A | 7.7 | 3200 |
| 29 | CEA-410 | 8.2 | 4 | N6 | 10.0 | 2A | 12 | 3 | 3 | N/A | 8.6 | 1200 |
| 30 | CEA-410 | 8.2 | 4 | N6 | 10.0 | 4A | 8 | 9 | 1 | N/A | 7.9 | 4500 |
| 31 | CEA-410 | 8.2 | 4 | N6 | 10.0 | 3A | 8 | 13 | 13 | 1 | 8.7 | 4300 |
| 32 | CEA-410 | 8.2 | 4 | N6 | 10.0 | 3B | 8 | 8 | 9 | N/A | 7.7 | 2600 |
| 34 | FM-200 | 8.7 | 4 | N7 | 11.0 | 2 | 13 | 5 | 5 | N/A | 9.0 | 8100 |
| 35 | FM-200 | 8.7 | 4 | N7 | 10.0 | 2A | 12 | 2 | 2 | N/A | 8.6 | 1500 |

**Table 8. Large Fire Extinguishment Tests (continued)**

| Test | Agent | Agent Concentration (Design) | Number of Nozzles | Nozzle | Discharge Time (s) | Fire Scenario | Extinguishment Time (s) | | | | Agent Concentration (measured) (%) | HF Concentration (measured) (ppm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | **1** | **2** | **3** | **4** | | |
| 36 | FM-200 | 8.7 | 4 | N7 | 10.0 | 4A | 12 | 14 | 2 | N/A | 8.7 | 3700 |
| 37 | FM-200 | 8.7 | 4 | N7 | 10.0 | 4 | 15 | N/A | N/A | N/A | 8.8 | 2400 |
| 38 | FM-200 | 8.7 | 4 | N7 | 10.0 | 3A | 7 | 9 | 15 | 2 | 8.7 | 5000 |
| 39 | FM-200 | 8.7 | 4 | N7 | 10.0 | 3B | 3 | 11 | 9 | N/A | 8.1 | 3900 |
| 40 | FM-200 | 8.7 | 4 | N7 | 10.0 | 3 | 4 | 12 | 12 | N/A | 8.2 | 3900 |
| 41 | FM-200 | 8.7 | 4 | N7 | 9.6 | 2 | 9 | 2 | 2 | N/A | 7.7 | 3600 |
| 46 | Envirogel | 5.0 | 2 | N9 | ? | 3B | 10 | 10 | NO | N/A | 5.0 | 5800 |

### 9.1.1 Freeburn Tests

A total of six freeburn tests were conducted during this test series. These tests consisted of the three original large fires required by the IMO test protocol (Scenarios 2, 3, and 4). It was originally intended to allow these fires to freeburn for a period of five minutes. However, one of the component fires in each of the three fire scenarios had self-extinguished due to oxygen depletion prior to the allotted time. During the freeburn of Scenario 2, the two large spray fires on top of the mockup self-extinguished approximately 1:00 after the vent openings were secured. The spray fire on the side of the mockup in Fire Scenario 3 self-extinguished in 1:30, and the large pan fire located in the bilge in Scenario 4 self-extinguished in 3:30. The bilge fires in general were observed to decrease in size as a function of the burn time. It is presumed that the size of the fire is reduced due to the oxygen depletion in the bilge (localized).

The oxygen concentrations measured during the freeburns of Fire Scenarios 2, 3, and 4 are shown in Figure 6. Due to the size of the fires and the lack of ventilation in the compartment, some degree of oxygen depletion will always occur during these tests. This is important relative to applying the results to larger compartments or to smaller fire scenarios where less oxygen depletion will occur.

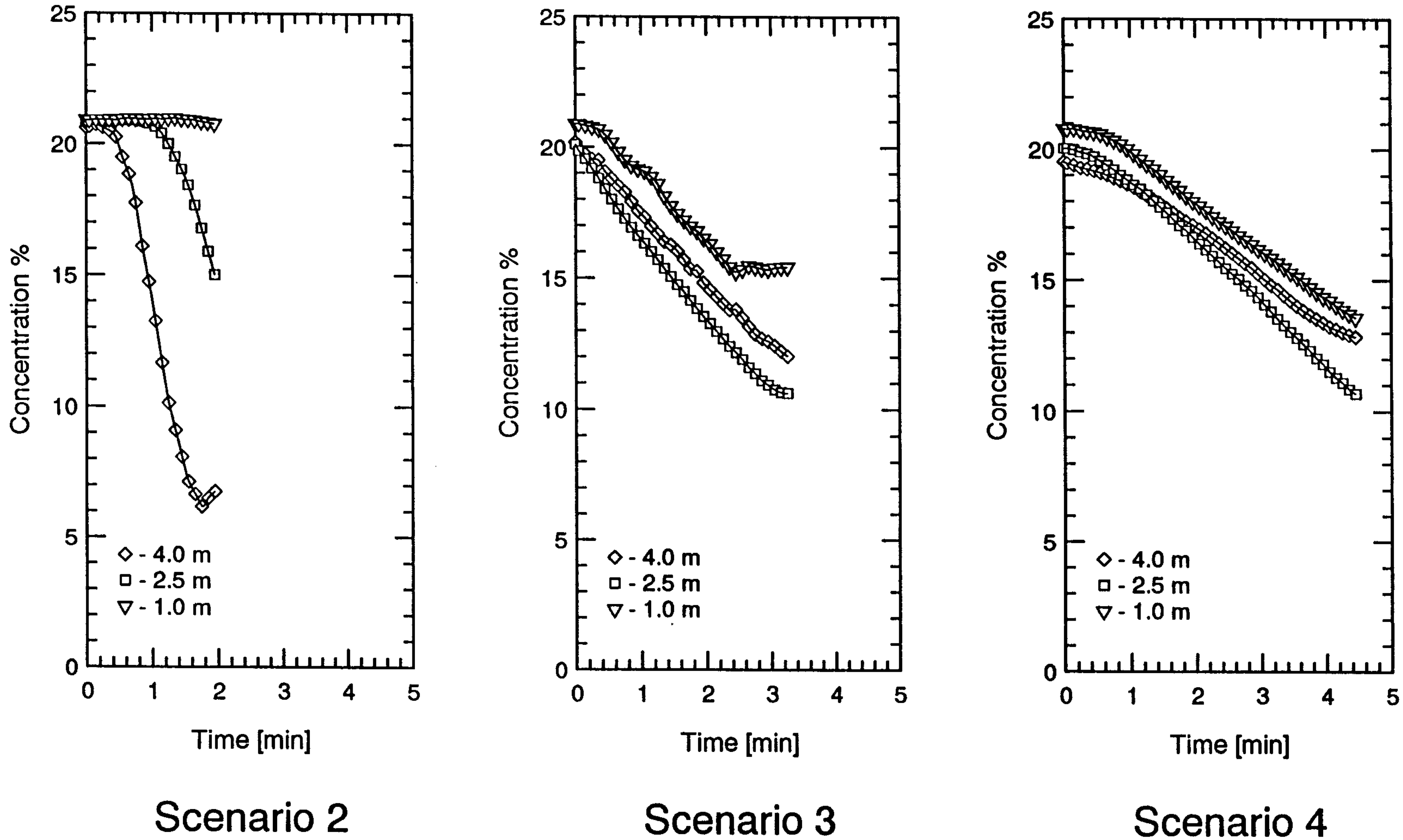



Figure 6. Oxygen concentration histories (freeburn)

### 9.1.2 Halon 1301 Extinguishment Tests

A total of three Halon 1301 Tests were conducted during this test series. All three tests were large fire extinguishment tests and were conducted against Fire Scenarios 2-4 of the original IMO test protocol. Halon 1301 was evaluated using a two-nozzle system. The design concentration for these tests was 5.0 percent at 24°C, which is 143 percent of the cup burner concentration. These tests served as a baseline for comparison to evaluate the other candidate agents.

The extinguishment times for these tests are shown in Table 8. During the evaluation against Fire Scenario 2, both unobstructed spray fires were extinguished almost instantly (2 seconds) and the shielded heptane pan fire was extinguished in 15 seconds. When evaluated against Fire Scenario 3, the wood crib was extinguished in 5 seconds, the diesel pan fire was extinguished in 10 seconds, and the shielded heptane spray fire was extinguished in 11 seconds. Through these tests, it was difficult to determine an exact extinguishment time for the fires conducted in the bilge. For all the agents evaluated in this test series, the bilge fires were extinguished close to the end of agent discharge (10 seconds).

### 9.1.3 CEA-410 Extinguishment Tests

A total of eight CEA-410 tests were conducted during this test series. The eight tests consisted of the original four IMO tests (Fire Scenarios 1-4), the three proposed IMO tests (Fire Scenarios 2A-4A), and a baseline test similar to Fire Scenario 3 (Scenario 3B). A four-nozzle system design was used in this evaluation. CEA-410 was capable of extinguishing all eight telltale fires during the first telltale fire test. The extinguishment times for the large fire tests are shown in Table 8. The design concentration for the large fire tests was 8.2 percent, which is 140 percent of the concentration used in the telltale fire test. During the Fire Scenario 2 test, the two unobstructed spray fires located on top of the mockup were extinguished almost instantly (2 seconds) and the shielded heptane pan fire located on the side of the mockup was

extinguished in 12 seconds. In the Fire Scenario 3 test, the wood crib was extinguished in 4 seconds and the unobstructed diesel pan fire and the shielded heptane spray fire were both extinguished in 9 seconds. In the bilge fire scenario (Scenario 4), the fire was extinguished close to the end of agent discharge (12 seconds).

The extinguishment times of the proposed IMO fire scenarios were similar to the original IMO fires. During the Fire Scenario 2A test, the spray fires on top of the mock up were extinguished almost instantly (3 seconds) and the shielded heptane pan fire was extinguished in 12 seconds. In the Fire Scenario 3A test, the wood crib was extinguished in 8 seconds, the shielded heptane pan fire was distinguished in 13 seconds and the unobstructed heptane pan fire (bilge) was extinguished in 13 seconds. The proposed bilge fire scenario (Scenario 4A) was also extinguished close to the end of agent discharge (9 seconds).

### 9.1.4 Envirogel Extinguishment Tests

A total of five tests were conducted with the Envirogel agent. The five tests consisted of four telltale fires and the baseline large fire test (Scenario 3B). Three additional telltales were added to Fire Scenario 1 to evaluate the agents'/systems' ability to extinguish obstructed fires. Envirogel was evaluated using a generic two-nozzle system.

During the first telltale fire test, Envirogel was only capable of extinguishing 4 of the 8 telltale fires. Only the 4 telltales on the lower deck were extinguished. The nozzles used during the first test were then modified (4 additional holes) in an attempt to distribute the agent high in the corners of the space. During the second telltale fire test, Envirogel was capable of extinguishing 5 of the 8 telltale fires. The modifications to nozzles resulted in the extinguishment of 2 of the 4 telltale fires located high in the space, but reduced the capabilities against the lower telltale fires (3 of 4 extinguished). During the next two tests, the discharge cylinders were changed from the 254 L Chubb cylinders to the 600 lb Ansul cylinders. During the third telltale test, Envirogel was capable of extinguishing all the required telltale fires (the 8 telltales in the

corners), but could only extinguish one of the three additional obstructed telltale fires. The remaining two fire tests (one telltale and one large fire test) were conducted with HFC-125 as the expellant gas rather than HFC-134A. During the final telltale fire test, Envirogel was capable of extinguishing 6 of the 8 telltales. During this test, the 4 telltales high in the space, and two of the four telltales on the lower deck were extinguished.

Envirogel was only evaluated against one of the large fire scenarios (Fire Scenario 3B). The extinguishment times for the large fire test are shown in Table 8. During this test, the wood crib fire was extinguished in 10 seconds, the unobstructed diesel pan fire was extinguished in 10 seconds, but the shielded heptane spray fire was not extinguished.

The results of the tests conducted with Envirogel demonstrate that the extinguishment capabilities of the system/agent are strongly dependent on agent distribution and the distribution system. Without an understanding of the dynamics associated with mixing this agent uniformly throughout the compartment, it is extremely difficult to design and evaluate such a system. Consequently, further research is needed before Envirogel can be considered for machinery space total flooding applications.

#### 9.1.5 FM-200 Extinguishment Tests

A total of nine FM-200 tests were conducted during this test series. The nine tests consisted of the original four IMO tests (telltales and Fire Scenarios 2-4), the three proposed IMO tests (Fire Scenarios 2A-4A) and a baseline test similar to Fire Scenario 3 (Scenario 3B). A four-nozzle system design was used in this evaluation.

FM-200 extinguished all eight telltale fires during the first telltale fire test. The extinguishment times for the large fire tests are shown in Table 8. The design concentration for the large fire tests was 8.7 percent, which is 130 percent of the concentration used in the telltale test. During the initial large fire test (Scenario 2), the two unobstructed spray fires located on top

of the mockup were extinguished in 5 seconds, and the shielded heptane pan fire located on the side of the mockup was extinguished in 13 seconds. The agent discharge time recorded during this test was approximately 11 seconds. The amount of HF produced during this test was about twice that produced by the other agents. Based on these results, a larger orifice area nozzle was used in the remaining tests. During the second evaluation against Fire Scenario 2, the two unobstructed spray fires were extinguished almost instantly (2 seconds) and the shielded heptane pan fire was extinguished in 9 seconds. The shorter discharge time (9.5 seconds) produced faster extinguishment times and less HF. When evaluated against Fire Scenario 3, the wood crib fire was extinguished in 4 seconds and the unobstructed diesel pan fire and the shielded heptane spray fire were extinguished in 12 seconds. The bilge fire scenario (Scenario 4) was extinguished shortly after agent discharge ($\approx$ 15 seconds).

The extinguishment times of the proposed IMO fire scenarios were similar to the original IMO fires. During the evaluation against Fire Scenario 2A, the spray fires on top of the mockup were extinguished almost instantly (2 seconds) and the shielded heptane pan fire was extinguished in 12 seconds. When evaluated against Fire Scenario 3A, the wood crib was extinguished in 7 seconds, the shielded heptane spray fire was extinguished in 9 seconds, and the obstructed heptane pan fire (bilge) was extinguished in 15 seconds. The proposed bilge fire scenario (Scenario 4A) was also extinguished shortly after the end of agent discharge (14 seconds).

### 9.1.6 NAF-SIII Extinguishment Tests

A total of fourteen NAF-SIII tests were conducted during this test series. The fourteen tests consisted of five telltale fire tests, six large IMO fire tests and three proposed IMO tests. A two-nozzle system design was used in this evaluation.

The manufacturers' representative from NAFGT took advantage of the opportunity to screen the mixing/distribution capabilities of various nozzles during the telltale fire tests. Of the

five nozzles evaluated during the telltale fire tests, two nozzles were selected for further evaluation (Nozzle N5, manufactured by NAFGT, and N1, a 3600 Ansul nozzle). The Ansul nozzle was evaluated against both the current and proposed IMO fire scenarios, and the NAFGT nozzle was evaluated against the original IMO fire scenarios.

The extinguishment times for these fires are shown in Table 8. The design concentration for these large fire tests was 12 percent, which is 120 percent of the concentration used in the telltale fire test. During the test conducted with the Ansul nozzle against Fire Scenario 2, the two unobstructed spray fires on top of the mockup were extinguished almost instantly (3 seconds), and the shielded heptane pan fire was extinguished in 10 seconds. When evaluated against Fire Scenario 3, all of the fires were extinguished in less than 5 seconds (wood crib fire, unobstructed diesel pan fire and the shielded heptane spray fire). As with the other agents, the bilge fire scenario (Scenario 4) was extinguished close to the end of agent discharge (9 seconds).

The extinguishment times recorded during the tests conducted with the Ansul nozzle (N1) in the proposed fire scenarios tests were similar to the original IMO fires. During the Fire Scenario 2A test, the two unobstructed spray fires were extinguished in 4 seconds and the shielded heptane pan fire was extinguished in 11 seconds. In the Fire Scenario 3A test, the wood crib fire and unobstructed diesel pan fire were both extinguished in 8 seconds and the shielded heptane pan fire was extinguished in 14 seconds. The proposed bilge fire (Scenario 4A) was extinguished close to the end of agent discharge (11 seconds).

The NAFGT nozzle (N5) produced similar extinguishment times but greater quantities of decomposition products. In the Fire Scenario 2 test, the shielded heptane pan fire was extinguished instantly and the two unobstructed spray fires on top of the mockup were extinguished in 5 seconds. In the Fire Scenario 3 test, all three fires were extinguished in 4 seconds. The bilge fire (Fire Scenario 4) was extinguished close to the end of agent discharge.

### 9.1.7 The Effects of Fire Size on Extinguishment Times

The extinguishment times recorded during this test series are plotted versus fire size in Figure 7. Due to the ventilation conditions in the space prior to agent discharge and the rapid extinguishment of these fires, there was no correlation between fire size and extinguishment time observed during these tests. However, since the protocol can be used to evaluate inert gases, the overall trends and related variables need to be discussed.

The primary variable associated with the relationship of extinguishment time and fire size is the compartment oxygen concentration. As the oxygen concentration is reduced, the difference between the oxygen concentration in the compartment and the limiting oxygen index for the fuel decreases [7 and 8]. This reduces the agent concentration needed for extinguishment and typically leads to shorter extinguishment times.

During these tests, the oxygen concentrations just prior to agent discharge are still relatively near ambient levels. The oxygen concentrations measured in this space after agent discharge are listed in Table 9. Also shown in Table 9 are the theoretical concentrations which would result from the displacement/dilution of the oxygen by the agent. These two values are in agreement for the majority of the telltale fire tests (Fire Scenario 1). The difference in the theoretical and measured values for the large fire tests is related to the size of the fire and the extinguishment time. The oxygen concentrations measured during extinguishment ranged from 13-18 percent. The limiting oxygen index for most hydrocarbon fuels is around 13 percent [7 and 8].

Although no correlation was observed between fire size and extinguishment time for the halocarbon agents, the size of these fires would have dramatically affected the evaluation of inert gases. The free burn tests show that two of the three larger fires included in the IMO test protocol would have self-extinguished prior to the time allotted to discharge the inert gases.

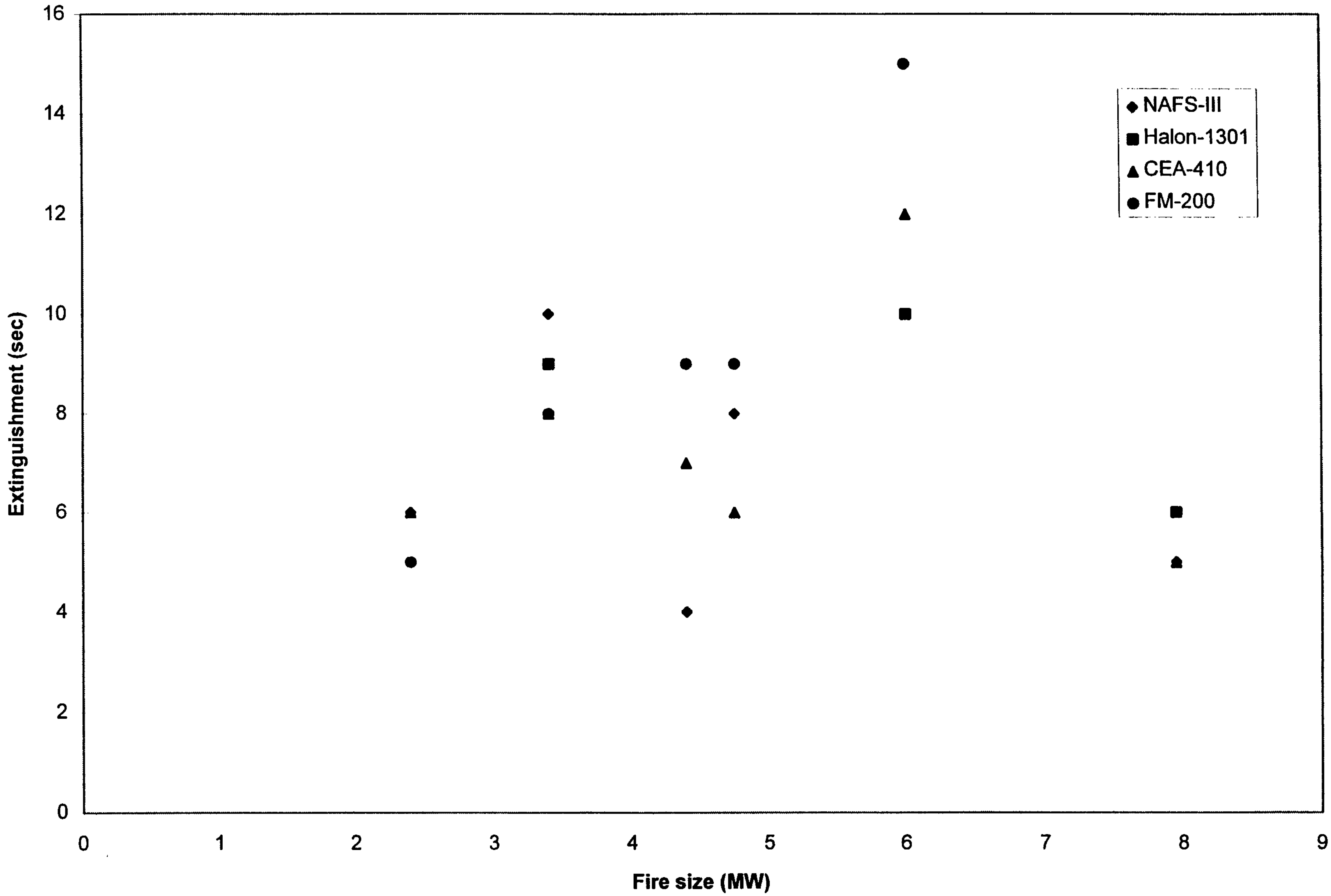



Figure 7. Extinguishment time comparison

**Table 9. Agent and Oxygen Concentrations**

| Test | Agent | Number of Nozzles | Nozzle | Fire Scenario | Discharge Time (s) | Agent Concentration (Design) | Actual Concentration (Measured) (%) | Oxygen Concentration (Theoretical) (%) | Oxygen Concentration (Measured) (%) | Compartment Pressures (kPa) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | Positive | Negative |
| 8 | NAF-SIII | 2 | N1 | 1 | 9.5 | 10 | 8.6 | 18.9 | 18.3 | 0.1 | -0.2 |
| 9 | NAF-SIII | 2 | N2 | 1 | 9.5 | 10 | 9.3 | 18.9 | 18.3 | 0.0 | 0.0 |
| 10 | NAF-SIII | 2 | N2 | 1 | 9.5 | 10 | 9.2 | 18.9 | 18.3 | 0.0 | 0.0 |
| 11 | NAF-SIII | 2 | N3 | 1 | 9.5 | 10 | 8.6 | 18.9 | 18.3 | 0.1 | 0.0 |
| 12 | NAF-SIII | 2 | N1 | 2 | 9.5 | 12 | 11.8 | 18.5 | 14.8 | 0.75 | >-1.25 |
| 13 | NAF-SIII | 2 | N1 | 3B | 9.5 | 12 | 10.8 | 18.5 | 15.3 | 1.0 | >-1.25 |
| 14 | NAF-SIII | 2 | N1 | 4 | 9.5 | 12 | 11.8 | 18.5 | 15.1 | 0.4 | >-1.25 |
| 15 | Halon | 2 | N4 | 2 | 9.5 | 5 | 4.6 | 20.0 | 16.5 | 0.0 | -1.5 |
| 16 | Halon | 2 | N4 | 3B | 9.5 | 5 | 4.8 | 20.0 | 17.3 | 0.0 | 0.0 |
| 17 | Halon | 2 | N4 | 4 | 9.0 | 5 | 4.7 | 20.0 | 17.0 | 0.5 | 1.5 |
| 18 | NAF-SIII | 2 | N5 | 1 | 9.2 | 10 | 9.2 | 18.9 | 17.8 | 0.1 | 0.0 |
| 19 | NAF-SIII | 2 | N5 | 2 | 9.2 | 12 | 12.2 | 18.5 | 14.7 | 0.5 | -4.2 |
| 20 | NAF-SIII | 2 | N5 | 3B | 9.0 | 12 | 11.6 | 18.5 | 14.3 | 0.4 | -3.0 |
| 21 | NAF-SIII | 2 | N5 | 4 | 9.0 | 12 | 10.2 | 18.5 | 13.6 | 0.25 | -2.5 |
| 22 | NAF-SIII | 2 | N1 | 2A | 10.0 | 12 | 12.7 | 18.5 | 16.0 | 0.25 | -2.5 |
| 23 | NAF-SIII | 2 | N1 | 3A | 10.5 | 12 | 12.3 | 18.5 | 12.8 | 0.5 | -2.5 |
| 24 | NAF-SIII | 2 | N1 | 4A | 10.5 | 12 | 12.3 | 18.5 | 13.0 | 0.25 | -2.7 |
| 25 | CEA-410 | 4 | N6 | 1 | 11.0 | 5.9 | 5.8 | 19.8 | 19.2 | 0.1 | 0.0 |
| 26 | CEA-410 | 4 | N6 | 2 | 11.0 | 8.2 | 7.9 | 19.3 | 16.4 | 0.75 | -6.2 |
| 27 | CEA-410 | 4 | N6 | 4 | 10.0 | 8.2 | 8.7 | 19.3 | 15.0 | 0.75 | -6.2 |
| 28 | CEA-410 | 4 | N6 | 3 | 10.0 | 8.2 | 7.7 | 19.3 | 16.0 | 0.3 | -2.0 |

**Table 9. Agent and Oxygen Concentrations (Continued)**

| Test | Agent | Number of Nozzles | Nozzle | Fire Scenario | Discharge Time (s) | Agent Concentration (Design) | Actual Concentration (Measured) (%) | Oxygen Concentration (Theoretical) (%) | Oxygen Concentration (Measured) (%) | Compartment Pressures (kPa) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | Positive | Negative |
| 29 | CEA-410 | 4 | N6 | 2A | 10.0 | 8.2 | 8.6 | 19.3 | 17.5 | 0.0 | -0.75 |
| | CEA-410 | 4 | N6 | 4A | 10.0 | 8.2 | 7.9 | 19.3 | 13.8 | 0.25 | -3.5 |
| 31 | CEA-410 | 4 | N6 | 3A | 10.0 | 8.2 | 8.7 | 19.3 | 14.3 | 0.0 | -3.8 |
| | CEA-410 | 4 | N6 | 3B | 10.0 | 8.2 | 7.7 | 19.3 | 16.7 | 0.5 | -3.0 |
| 33 | FM-200 | 4 | N7 | 1 | 11.0 | 6.7 | 6.6 | 19.6 | 18.8 | 0.0 | 0.0 |
| 34 | FM-200 | 4 | N7 | 2 | 11.0 | 8.7 | 9.0 | 19.2 | 15.1 | 0.5 | -0.75 |
| 35 | FM-200 | 4 | N7 | 2A | 10.0 | 8.7 | 8.6 | 19.2 | 17.0 | 0.25 | -0.75 |
| 36 | FM-200 | 4 | N7 | 4A | 10.0 | 8.7 | 8.7 | 19.2 | 14.5 | 0.5 | -3.0 |
| 37 | FM-200 | 4 | N7 | 4 | 10.0 | 8.7 | 8.8 | 19.2 | 16.0 | 0.25 | -2.25 |
| 38 | FM-200 | 4 | N7 | 3A | 10.0 | 8.7 | 8.7 | 19.2 | 14.5 | 0.5 | -3.8 |
| 39 | FM-200 | 4 | N7 | 3B | 10.0 | 8.7 | 8.1 | 19.2 | 16.0 | 0.5 | -2.0 |
| 40 | FM-200 | 4 | N7 | 3 | 10.0 | 8.7 | 8.2 | 19.2 | 16.3 | 0.5 | -2.25 |
| 41 | FM-200 | 4 | N7 | 2 | 9.5 | 8.7 | 7.7 | 19.2 | 16.1 | 0.5 | -0.75 |
| 42 | Envirogel | 2 | N8 | 1 | ? | 5.6 | 5.6 | 19.8 | 19.6 | 0.0 | 0.0 |
| 43 | Envirogel | 2 | N9 | 1 | ? | 5.6 | 5.6 | 19.8 | 19.2 | 0.0 | 0.0 |
| 44 | Envirogel | 2 | N9 | 1 | ? | 5.6 | 5.3 | 19.8 | 19.2 | 0.0 | 0.0 |
| 45 | Envirogel | 2 | N9 | 1 | ? | 5.6 | 4.4 | 19.8 | 19.1 | 0.0 | 0.0 |
| 46 | Envirogel | 2 | N9 | 3B | ? | 5.0 | 6.1 | 20.2 | 18.3 | 0.25 | -3.0 |

### 9.1.8 The Effect of Discharge Time on Extinguishment Time

As the agent discharge time decreases, the extinguishment time should also decrease. This result is expected since for shorter discharge times, the extinguishing concentration is attained faster. Shorter discharge times also give rise to higher turbulence levels and possible flame blow-off, which will also reduce the extinguishment time. Both of these conditions were observed during the tests conducted with FM-200.

During the initial large fire test conducted with FM-200 (Scenario 2), the discharge time was approximately 11 seconds (the upper limit on discharge time). During this test, the two spray fires on top of the mockup were extinguished in 5 seconds and the shielded heptane pan fire on the side of the mockup was extinguished in 13 seconds. The test was then conducted with a higher flow nozzle to shorten the discharge time (9.5 seconds). During this test, the two spray fires were extinguished almost instantly (2 seconds) and the shielded heptane pan fire was extinguished in 9 seconds. The reduction in the spray fire extinguishment times is believed to be related to increased turbulence and the reduction in the pan fire extinguishment times is believed to related to achieved an extinguishment concentration.

### 9.1.9 Effects of Design Concentration on Extinguishment Time

During these tests, the candidate agents were evaluated at the manufacturers' recommended design concentrations. These concentrations ranged from 120 to 140 percent of the concentration used during the telltale fire tests. The agent concentration used during the telltale fire tests was typically the cup burner extinguishment concentration for either n-heptane or diesel fuel. The agent concentrations used during these test are shown in Table 1.

Previous studies have shown the inverse relationship between agent concentration and extinguishment times [6]. The extinguishment time asymptotically approaches zero as the design concentration increases. When the design concentration approaches 120-130 percent of the cup

burner number, the extinguishment time approaches the end of the discharge time, with further reductions only at marked increases in agent concentration. During this investigation, all the halocarbon agents were evaluated with concentrations equal to or greater than 120 percent of the cup burner concentration. Consequently, the extinguishment times were comparable between agents (all the fires were typically extinguished in 15 seconds).

#### 9.1.10 Extinguishment Summary

The three candidate gaseous halon alternatives (CEA-410, FM-200, and NAF-SIII) were capable of extinguishing all of the fires conducted in this investigation. Envirogel (the gas powder mix) was only evaluated against one large fire due to the poor performance observed during the telltale evaluation (Scenario 1). The extinguishment times were comparable between agents and fire sizes. The unobstructed fires were quickly extinguished (2-5 seconds), while the shielded and obstructed fires were extinguished near the end of agent discharge (10-15 seconds). The trends found throughout the literature with respect to agent concentration and discharge time were observed during this test series. However, due to the similarities in design concentrations and discharge times, the trends did not significantly effect one agent more than another. In short, CEA-410, FM-200 and NAF-SIII have successfully completed the IMO test protocol for gaseous agents.

### 9.2 Discharge System Evaluation

Two balanced discharge systems (two and four nozzles) were used in this evaluation. These systems were shown in Figure 1. Both systems meet the IMO requirement of uniformly spaced ceiling mounted nozzles. The parameters associated with these systems are discussed in the following sections.

### 9.2.1 Discharge Characteristics/Times

The discharge systems evaluated during these tests were designed and installed by the agent manufacturer. The specifics of each system are shown in Table 10. The systems were designed to produce a 10 second discharge time ±1 second.

The actual discharge times were determined from the pressure measurements taken at the nozzle during these tests. The nozzle pressures measured during these tests ranged from 690 kPa for FM-200 to as high as 1655 kPa for Halon 1301. The nozzle pressures recorded during these tests are also shown in Table 10. The discharge time was defined as the time from when the nozzle first showed any increase in pressure until the inflection in the pressure plot signaling the beginning of liquid agent run out. The discharge times determined using this technique are also shown in Table 8. It should be noted that the agent discharge cylinders were filled to the design pressure at ambient conditions at one of the three filling locations. The pressure in the cylinders just prior to system discharge was a function of the ambient conditions on the test ship. The net result was a cylinder pressure usually 10-15 percent higher than the design pressure.

As shown in Table 8, the discharge times observed for the halocarbon agents were all within the design constraints listed in the test protocol. Kidde-Fenwal (FM-200) and NAFGT (NAF-SIII) did, however, elect to increase the orifice area of the nozzle to reduce the discharge time, but still remained within the published limits. The discharge times for Envirogel could not be determined by the pressure plots. The flow of the powder through the pipe fluctuated significantly resulting in an irregular shaped pressure plot. In a majority of the tests with Envirogel, significant amounts of agent also remained in the cylinder after discharge.

**Table 10. Discharge System Results**

| Agent | Fire/Test | Conc. (%) | Agent Weight (kg (lb)) | Cylinder Size | No. of Cylinders | Pipe Size (in.) | | | No. of Nozzles | Nozzle Area ($cm^2$ ($in.^2$)) | Average Nozzle Pressure (kPa (psi)) | Discharge Time(s) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | A | B | C | | | | |
| Halon | All | 5.0 | 155 (340) | 600 lb | 1 | 3 | 2 | | 2 | 2.23 (1.12) | 1655 (240) | 9.5 |
| CEA-410 | Telltales | 5.9 | 312 (686) | 350 lb | 3 | 3 | 2½ | 2 | 4 | 4.65 (0.72) | 1103 (160) | 10.0 |
| CEA-410 | Large Fires | 8.2 | 444 (977) | 350 lb | 3 | 3 | 2½ | 2½ | 4 | 10.13 (1.57) | 965 (140) | 10.0 |
| FM-200 | Telltales | 6.7 | 262 (576) | 350 lb | 2 | 3 | 2½ | 2 | 4 | 7.23 (1.12) | 690 (100) | 11.0 |
| FM-200 | Large Fires | 8.7 | 349 (768) | 350 lb | 3 | 3 | 2½ | 2 | 4 | 12.90 (2.0) | 690 (100) | 10.0 |
| NAF-SIII | Telltales | 10 | 215 (473) | 600 lb | 1 | 3 | 2 | | 2 | 17.10 (2.65) | 896 (130) | 10.5 |
| NAF-SIII | Large Fires | 12 | 264 (580) | 600 lb | 2 | 3 | 2 | | 2 | 21.16 (3.28) | 1034 (150) | 9.5 |
| Envirogel | All | 4.6/160 $g/m^3$ | 205 (450) | 600 lb | 1 | 3 | 2½ | | 2 | 15.89 (2.46) | 1034 (150) | 8.0 |

### 9.2.2 Mixing Characteristics/Telltale Fire Tests

Typically, the mixing characteristics of a system are measured during cold discharge tests instrumented with multiple agents concentration sampling locations. During this investigation, the cold discharge tests were abandoned on the premise that the telltale fire tests provide similar information pertaining to mixing characteristics of the systems.

The results of the telltale fire tests are shown in Table 7. The failure rate observed during these tests (~50 percent) illustrates the difficulty in designing these systems even in a relatively empty machinery space. The mixing characteristics of agents are primarily related to the system design parameters (nozzle type, size and spacing). IMO's approach of using the minimum extinguishment concentration during these tests increases the difficulty of the test and provides a factor of safety when designing a system for an actual machinery space. However, the ability to achieve an extinguishment concentration in all locations in a highly cluttered space is not evaluated.

### 9.2.3 Agent Concentration

Agent concentration measurements were made during these tests using two KVB/Analect Diamond 20s (FTIRs). The agent concentrations were determined by comparison with spectra obtained using known concentrations. The wave numbers used to determine the concentrations for each agent are found in Section 7.2.2 of this report. The FTIR measurements were also adjusted based on the temperatures in the space (density adjustments). The agent design concentrations and measured concentrations for the various tests are shown in Table 9. Plots of agent concentration versus time are found in Appendix C.

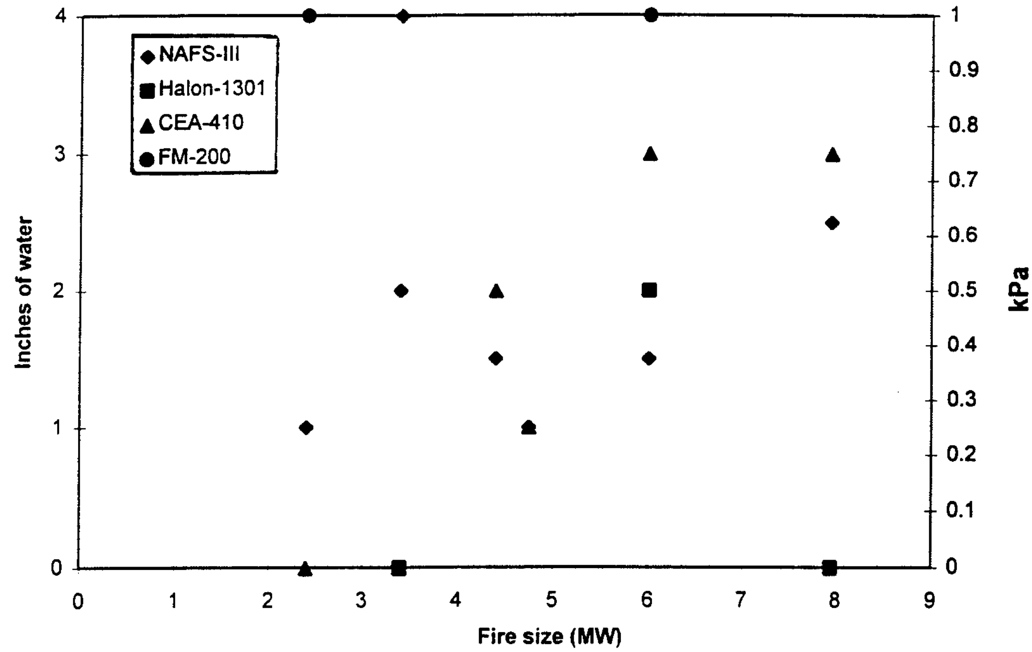
The values shown in Table 9 are the five-minute average agent concentrations. The five minute average is usually slightly less than the design concentration due to compartment leakage and consumption of the agent by the fire. As shown in Table 9, the measure of concentrations

are in agreement with the design concentration with a few exceptions. During three of the 14 tests conducted with NAF-SIII (Tests 8, 11, and 21), the measured concentration was 15 percent less than the design concentration. This was attributed to agent losses out of the vertical stack due to increases in compartment pressure (pressure venting). These damper problems were fixed prior to the evaluation of the next agent.

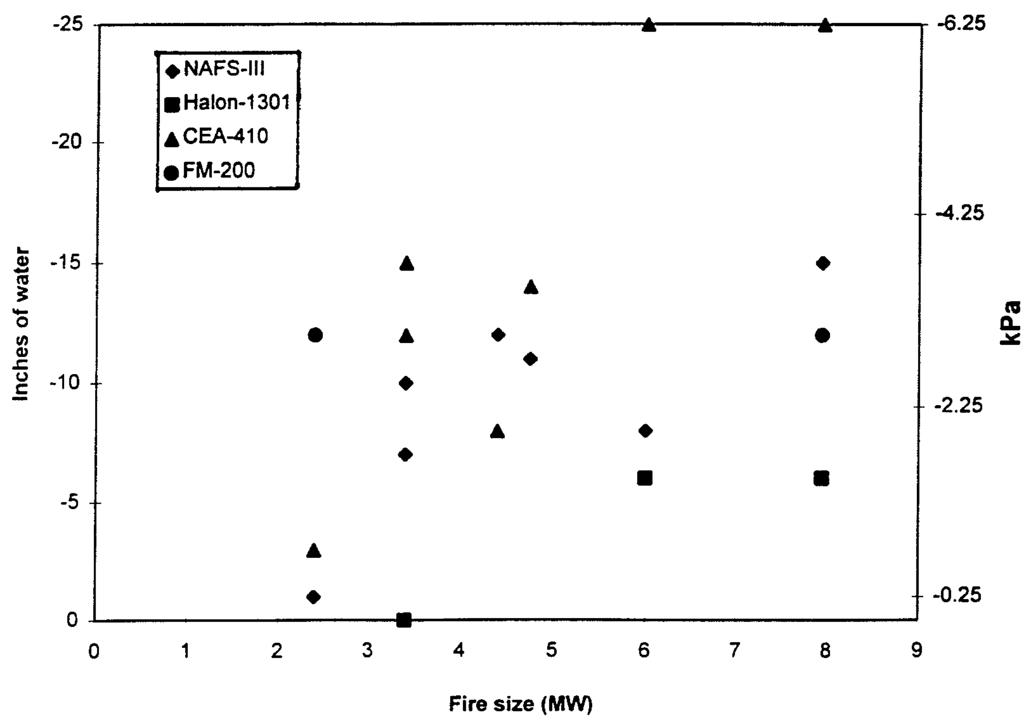
### 9.2.4 Compartment Pressure Evaluation

The compartment pressures measured during these tests are listed in Table 7 and shown in Figure 8. The compartment pressures generated are functions of the enclosure volume, agent concentration, discharge time, leakage area, and fire size. When a gaseous agent that is stored as a liquid is discharged into a compartment, the compartment initially develops a negative pressure due to the rapid cooling of the gases in the enclosure as the agent flashes to a vapor. When the flow of agent into the compartment changes from predominantly liquid to predominantly vapor (nozzle liquid runout), the compartment pressure changes from negative to positive. Without the heat absorption provided by the vaporization of the liquid, the agent is unable to counteract the heat transfer from the walls of the compartment and the continuing addition of agent.

The agent flow rate into the enclosure and the leakage area counterbalance each other in determining the enclosure pressures. Increasing the agent flow rate (by enclosure volume, increasing agent concentration, and/or reducing discharge time) increases the magnitude of both the negative and positive pressures experienced. Increasing the leakage area reduces the magnitude of the pressures experienced.




8a Positive pressures




8b Negative pressures

Figure 8 Compartment Pressure Comparison

The presence of a fire plays a complex role through two effects. The fire preheats the enclosure, increasing the temperature and reducing the mass of air in the enclosure. The reduced mass causes an increase in the magnitude of the negative pressure experienced upon discharge of the agent. The increased temperature of the boundaries (the temperature of the gas to a lesser extent) increases the heat transfer to the gas, causing a faster change-over to positive pressure and increases the magnitude of the resultant pressure. The second effect is due to the continued burning during the beginning of the discharge. The heat added will move both pressures in the positive direction (reduce the negative and increase the positive). As this heat is added at the beginning of the discharge, the effect is most apparent on the negative pressure. Depending upon the size and duration of the continued burning, the negative pressure pulse can be delayed and/or reduced. The role of the fire size on enclosure pressure is illustrated by the differences in pressures reported between the telltale and fire tests and between the different fire scenarios in Figure 8. Negative pressures as low as -6.2 kPa and positive pressures as high as 0.75 kPa were measured during these tests. It should be noted that the damper in the vertical stack was only held down by gravity, and consequently, the positive pressure component may have been vented off for pressures above 0.75 kPa (3 IWC).

On a final note, the current IMO test protocol requires the measurement of compartment pressure but does not identify a range of acceptable values. These pressure excursions should be considered an important design parameter for gaseous agent systems.

## 9.3 Decomposition Products

### 9.3.1 Hydrogen Fluoride (HF) Production and Decay

The HF concentrations measured during these tests are shown in Table 8. Previous studies [6] have shown that HF production is related to fire size, discharge time, design, concentration, and extinguishment time. For similar fire sizes and discharge times, it appears that the gaseous halocarbon halon alternatives produce, in general, approximately 5-10 times more HF than Halon 1301. This is illustrated when comparing the five tests conducted against Fire Scenario 3B. During these tests, Halon 1301 produced a 5-minute average HF concentration on the order of 300 ppm as compared to 2300-5800 ppm for the alternative agents.

The HF concentration measurements recorded during these tests follow the same general trends with respect to production and decay as observed in previous studies. A typical HF concentration history is shown in Figure 9. Maximum HF concentrations were measured shortly after extinguishment and were observed to nominally decay 50 percent within 10 minutes. The agent concentrations only decayed a nominal 15 percent for the same period. The difference in decay rate is due to the condensing and plating out of the HF on the surfaces of the test compartment.

### 9.3.2 The Effects of Fire Size on HF Products

To illustrate the relation of HF production to fire size, the HF concentrations (five minute average) were plotted versus fire size normalized by the compartment volume in Figure 10. Also plotted on this figure is the linear relation previously developed during full- and intermediate-scale studies [6]. The HF produced during these tests appears to follow the same trends/relations found throughout the literature with the exception of the fires conducted on top

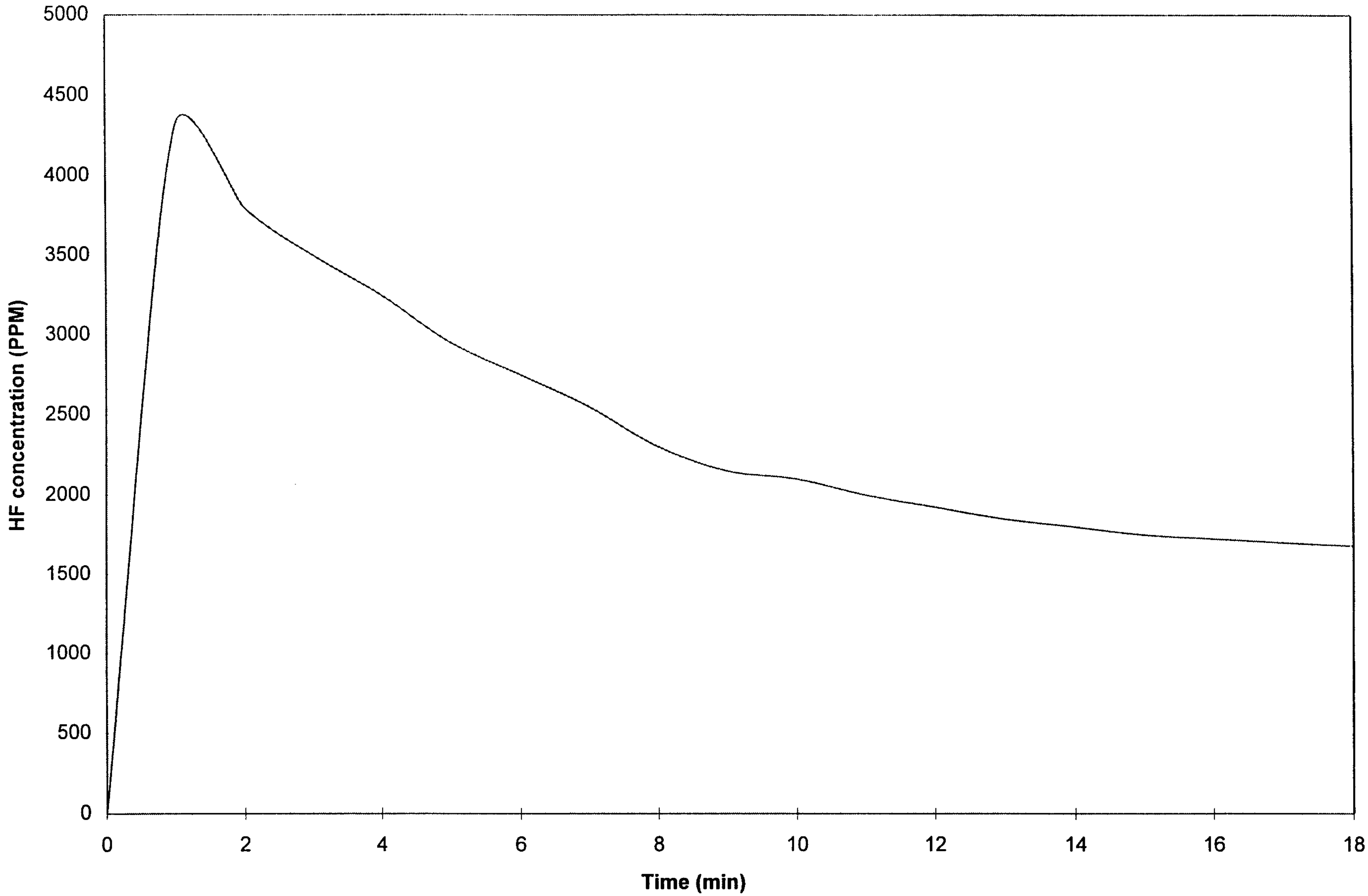



Figure 9. HF concentration history (typical)
(Test #31 - CEA-410 - fire scenario - 3A)

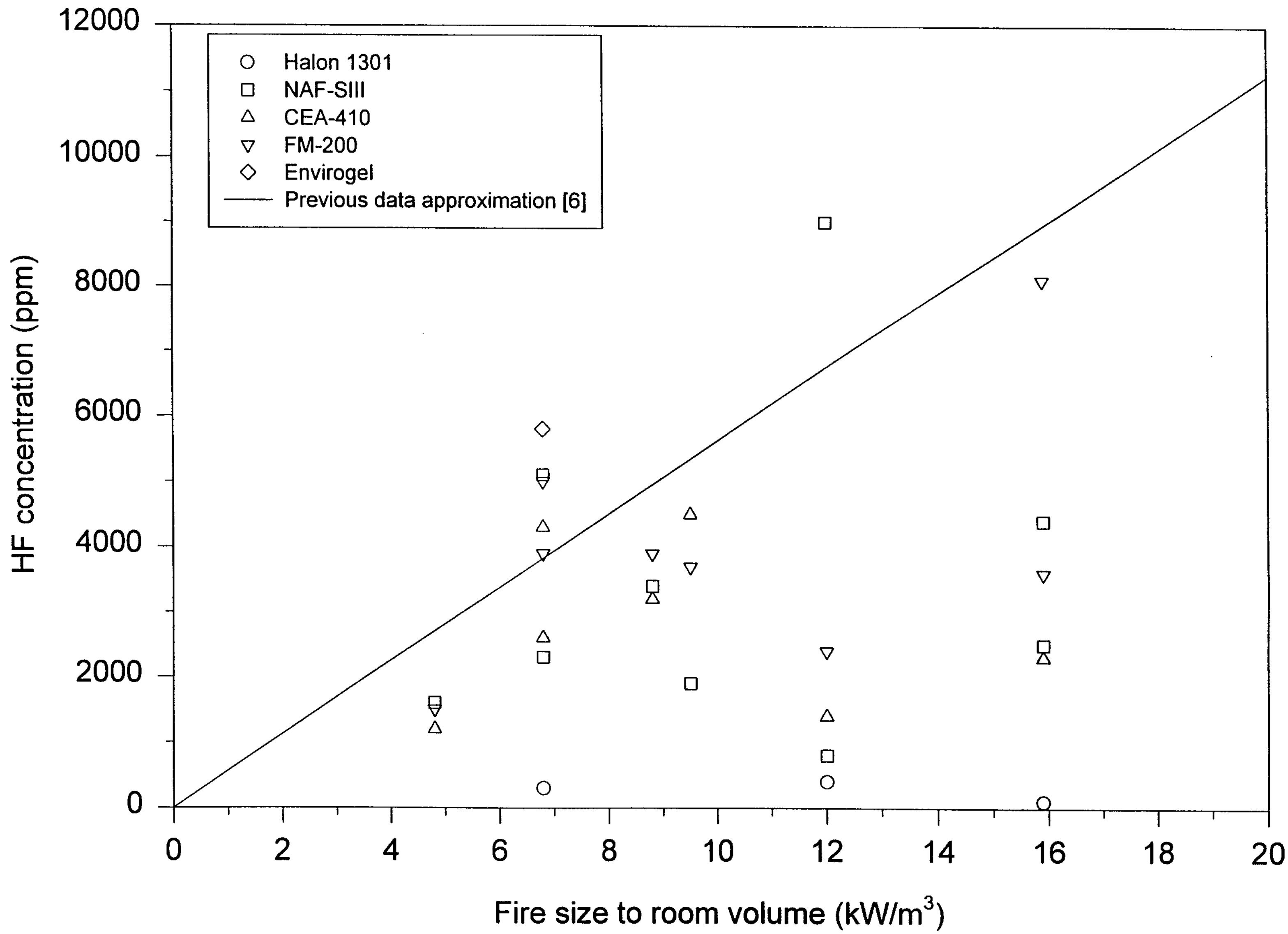



**Figure 10 HF Production**

of the mockup and the fires conducted in the bilge. These fires produced significantly less HF than expected for fires of this magnitude. These lower HF concentrations suggest that the fires on top of the engine mockup are being blown out, not extinguished by the effects of the agent. It also suggests that the lack of ventilation in the bilge is adversely effecting the size of the bilge fires. During one of the bilge fire tests (Test 21, NAF-SIII, N5), however, the turbulence created by the nozzles increased the air flow into the bilge and consequently increased the size of the fire. During this test, the amount of HF produced was approximately twice that of the other agents. It should be noted that these tests were conducted with agent design concentrations on the order of 1.2-1.4 times the cup burner concentrations, and all of these fires were extinguished during or shortly after agent discharge. Variations in extinguishment times and/or design concentrations may dramatically affect the HF production.

#### 9.3.3 Hydrogen Chloride (HCl/Production)

In addition to HF production, agents containing or consisting of chlorinated compounds need to be evaluated based on hydrogen chloride (HCl) production as well. Only one agent (NAF-SIII) evaluated during these tests contains chlorine. The HFC blend referred to as NAF-SIII contains chlorinated compounds (R22, R123, and R124). The HCl produced during the extinguishment of these fires using NAF-SIII is shown in Table 11. As shown in this table, similar amounts of HCl and HF are produced in each test.

**Table 11. Decomposition Product Summary** (NAF-SIII)

| Fire Scenario | Fire Size (MW) | Nozzle | Discharge Time | Average HF Conc. (ppm) | Average HCl Conc. (ppm) |
|---|---|---|---|---|---|
| 1 | 0.025 | N1 | 9.5 | Neg. | Neg. |
| 2 | 7.95 | N1 | 9.2 | 2500 | 2300 |
| 2 | 7.95 | N5 | 9.5 | 4400 | 4100 |
| 2A | 2.40 | N1 | 9.5 | 1600 | 1500 |
| 3A | 3.40 | N1 | 9.5 | 5100 | 5800 |
| 3B | 4.40 | N5 | 9.5 | 3400 | 2600 |
| 3B | 3.40 | N1 | 9.5 | 2300 | 2400 |
| 4 | 6.0 | N1 | 9.5 | 1000 | 500 |
| 4 | 6.0 | N5 | 9.0 | 9000 | 10000 |
| 4A | 4.75 | N1 | 9.5 | 1900 | 1700 |

Neg. - below 100 ppm

### 9.3.4 The Effects of Discharge and Extinguishment Time on HF Production

As stated previously, discharge and extinguishment times are primary variables in the production of HF for a given fire size to compartment volume ratio. This is illustrated when comparing the two tests conducted against Fire Scenario 2 using FM-200. With an 11-second discharge time, the unobstructed spray fires were extinguished in five seconds and the shielded heptane pan fire was extinguished in 13 seconds. The five minute average HF concentration was measured to be 8100 ppm. With a 9.5-second discharge time, the spray fires were extinguished in two seconds and the obstructed heptane pan fire was extinguished in nine seconds. The five minute average HF concentration was measured to be 3600 ppm. In summary, shortening the discharge time resulted in faster fire extinguishment and over a 50 percent reduction in HF production. This reduction in HF production is significantly higher than would typically be expected due to the 60 percent reduction in extinguishment time for the two spray fires which represent 95 percent of the total fire size of this scenario. These two spray fires were extinguished earlier in response to the increased turbulence on top of the mockup. It should be noted that in all testing with this scenario, with the exception of the 11-second discharge FM-200 test, extinguishment of these two fires occurred approximately two seconds into the discharge.

### 9.3.5 HF Production Summary

The HF concentrations measured during these tests followed the same trends found throughout the literature. For relatively quick extinguishment times (less than 15 seconds), the HF production appears to be approximately linear and a function of fire size to compartment volume ratio (as shown in Figure 10). The halocarbon agents evaluated in this test series (CEA-410, FM-200, and NAF-SIII) were capable of extinguishing these fires in this time frame.

The candidate agents produced 5-10 times the amounts of HF as Halon 1301 for the same fire size/scenario and similar extinguishment times. This substantial increase in HF production must be considered with respect to the exposure scenario and the unmitigated fire hazard.

Published data on HF [9.10] suggest that short exposures (one minute) to 250 to 1000 ppm can be dangerous to occupants of the space. Irritation is observed at concentrations of 100 ppm. Meldrum [10] has estimated the DLT or Dangerous Toxic Load for HF in humans to be 1000 ppm for a 10-minute exposure. Based on typical machinery space fires, it can be assumed that Halon 1301 has produced peak HF concentrations (in addition to HBr production) greater than these values. These high levels of HF occur in the presence of relatively large fires which by themselves pose immediate life threatening risks for persons located in the fire compartment. The hazard posed by HF must be evaluated in this context. Higher levels of HF relative to those experienced with Halon 1301 (and its associated HBr production) may require additional precautions for personnel reentering the space after a fire suppression event.

## 9.4 Fire Scenario Evaluation

An evaluation of the fire scenarios included in this investigation is provided in the following sections. The cold discharge test was not included during this evaluation based on the presumption that both the cold discharge test and the telltale fire test provide similar information.

### 9.4.1 Telltale Fire Tests

The telltale fire tests are intended to meet two objectives. The first is to validate the minimum extinguishment concentration based on a cup burner concentration. The second more important objective is to verify the ability of the nozzle to produce a uniform concentration of agent throughout the space. The agent discharge time and minimum average nozzle pressure should also be established during these tests.

The results of the telltale fire tests are shown in Table 7. The high failure rate observed during these tests (≈50 percent) suggests that this test was the most challenging for the agent and hardware combinations evaluated during this test series. Consequently, many of the manufacturers (i.e., NAFGT and Powsus, Inc.) used this test to screen candidate nozzle and

system designs. The telltales are currently positioned to evaluate if the discharge system distributes adequate amounts of agent in each of the eight corners of the space. No effort was made to evaluate the system's ability to distribute agent in the center of the space as well as into obstructed areas such as the bilge. During this evaluation, the telltales located high in the forward corners of the space were significantly more difficult to extinguish than those located high in the aft corners or those located on the lower deck. The forward corners high in the space were shielded from direct spray impingement from the discharge nozzles, adding additional difficulty and realism to fires conducted at this location.

The telltale fire scenario also proved beneficial in evaluating the capabilities of agents containing solid particulate. Agents containing solid particulate (i.e., Envirogel) are highly dependent on agent distribution for performance and were observed to have limited capabilities against obstructed fires. This was based on three additional telltale fires located in and around the bilge. During these tests, Envirogel had difficulty extinguishing all of the telltale fires.

### 9.4.2 Fire Scenario 2

The test results for Fire Scenario 2 (7.95 MW) are shown in Table 12. The results of the tests conducted against the proposed fire scenario, Scenario 2A (2.4 MW) are shown in Table 13. The extinguishment times recorded during these tests were similar between agents. The two spray fires on top of the mockup were typically extinguished in less than 5 seconds, and the heptane pan located under the 1.0 m obstruction plate was usually extinguished between 10 - 15 seconds from the beginning of agent discharge. The reignition procedure, as currently written, lacks a source with enough heat or energy to ignite the fuel spray. Consequently, reignition did not occur during any of the tests conducted during this test series. A new approach to the reignition evaluation such as an electrical resistance heater or spark ignition source should be considered. The short extinguishment times and their unobstructed proximity to the nozzle jets suggest that these spray fires are either being blown out or are located in areas of localized higher agent concentrations. Conversely, the heptane pan fire located under the obstruction plate was

not extinguished until the agent became more uniformly mixed throughout the space. Fires located high in the space may also be affected by the vitiated gases (low oxygen) comprising the hot layer. It is recommended that these fires be separated and baffled to prevent them from being blown out. Relocating them to a lower elevation is also an acceptable approach.

It should be noted that no major differences in extinguishment times were observed between Fire Scenarios 2 and 2A, even though the size of these fires was significantly different (2.5 times). The fire size was, however, related to the production of decomposition products and will be discussed in Section 9.6.

## Table 12. Fire Scenario 2 Extinguishment Summary

| Agent | NAF-SIII | NAF-SIII | Halon | CEA-410 | FM-200 | FM-200 |
|---|---|---|---|---|---|---|
| Agent Concentration (%) | 12 | 12 | 5 | 8.2 | 8.7 | 8.7 |
| Relative Concentration[(1)] | 1.2 | 1.2 | 1 | 1.4 | 1.3 | 1.3 |
| Number of Nozzles | 2 | 2 | 2 | 4 | 4 | 4 |
| Nozzle | N1 | N5 | N4 | N6 | N7 | N7 |
| Discharge Time (s) | 9.5 | 9.2 | 9.5 | 11.0 | 11.0 | 9.5 |
| Extinguishment Time (s)[(2)] Heptane pan fire (side) | 10 | 1 | 15 | 12 | 13 | 9 |
| Extinguishment Time (s)[(2)] Heptane spray fire (top) | 3 | 5 | 2 | 2 | 5 | 2 |
| Extinguishment Time (s)[(2)] Diesel spray fire (top) | 3 | 5 | 2 | 2 | 5 | 2 |
| Average Agent Conc. (%) 5:00 | 11.8 | 12.2 | 4.6 | 7.9 | 9.0 | 7.7 |
| Peak HF Conc. (ppm) 5:00 | 2500 | 4400 | 100 | 2300 | 8100 | 3600 |
| Positive Compartment Pressure (kPa (IWC)) | 0.75 (3) | 0.5 (2) | 0 (0) | 0.75 (3) | 0.5 (2) | 0.5 (2) |
| Negative Compartment Pressure (kPa (IWC)) | >1.25 (>5) | 4.2 (17) | 1.5 (6) | 6.2 (25) | 0.75 (3) | 0.75 (3) |
| Oxygen Conc. after Discharge (%)[(3)] | 14.8 | 14.7 | 16.5 | 16.4 | 15.1 | 16.6 |

Notes: (1) Relative concentrations are based on the telltale design concentration.
(2) Extinguishment times are measured from the beginning of agent discharge.
(3) After agent discharge, the oxygen concentration is relatively uniform throughout the compartment.

**Table 13. Fire Scenario 2A – Test Results**

| Agent | NAF-SIII | CEA-410 | FM-200 |
|---|---|---|---|
| Agent Concentration (%) | 12 | 8.2 | 8.7 |
| Relative Concentration[(1)] | 1.2 | 1.4 | 1.3 |
| Number of Nozzles | 2 | 4 | 4 |
| Nozzle | N1 | N6 | N7 |
| Discharge Time (s) | 10 | 10 | 10 |
| Extinguishment Time(s)[(2)] heptane pan fire (side) | 11 | 12 | 12 |
| Extinguishment Time(s)[(2)] Heptane spray fire (top) | 4 | 3 | 2 |
| Extinguishment Time(s)[(2)] Diesel spray fire (top) | 4 | 3 | 2 |
| Agent Conc. (%), 5:00 Average | 12.7 | 8.6 | 8.6 |
| HF Conc. (ppm), 5:00 Average | 1600 | 1200 | 1500 |
| Positive Compartment Pressure (kPa) | 0.25 | 0 | 0.25 |
| Negative Compartment Pressure (kPa ) | 0.25 | 0.75 | 0.75 |
| Oxygen Conc. after Discharge (%) | 16.0 | 17.5 | 17.0 |

Note: (1) Relative concentrations are based on the telltale design concentration.
(2) Extinguishment times are measured from the beginning of agent discharge.
(3) After agent discharge, the oxygen concentration is relatively uniform throughout the compartment.

### 9.4.3 Fire Scenario 3

The test results for Fire Scenarios 3 (4.4 MW), 3A (3.4 MW), and 3B are shown in Tables 14, 15, and 16, respectively. In all tests, the component fires were extinguished within 15 seconds of the beginning of agent discharge with the exception of one test conducted with Envirogel. Envirogel is a hybrid gaseous/powder agent that appears to be highly dependent on agent distribution for performance and was observed to have limited capabilities against obstructed fires. Consequently, Envirogel was not capable of extinguishing the shielded heptane spray fire in Fire Scenario 3.

With respect to the component fires associated with the various versions of Fire Scenario 3, the diesel and heptane pan fires located on top of the bilge plate were typically extinguished in just over ten seconds. The proposed heptane pan fire (Scenario 3A) located in the bilge required a few seconds longer to extinguish. Independent of fuel type and location, these pan fires appear to provide a challenge to the gaseous agent systems evaluated during this investigation.

**Table 14. Fire Scenario 3 – Test Results**

| Agent | CEA-410 | FM-200 |
|---|---|---|
| Agent Concentration (%) | 8.2 | 8.7 |
| Relative Concentration(1) | 1.4 | 1.3 |
| Number of Nozzles | 4 | 4 |
| Nozzle | N6 | N7 |
| Discharge Time (s) | 10 | 10 |
| Extinguishment Time(s) Wood crib (deck) | 4 | 4 |
| Wood Crib Mass Loss (%) | 36 | 41 |
| Extinguishment Time(s) Diesel pan fire (bilge plate)(2) | 9 | 12 |
| Extinguishment Time(s) Spray fire (side)(2) | 9 | 12 |
| Agent Concentration (%), 5:00 Average | 7.7 | 8.2 |
| HF Concentration (ppm), 5:00 Average | 3200 | 3900 |
| Positive Compartment Pressure (kPa) | 0.5 | 0.5 |
| Negative Compartment Pressure (kPa) | 2.0 | 2.25 |
| Oxygen Conc. after Discharge (%)(3) | 16.0 | 16.7 |

Note: (1) Relative concentrations are based on the telltale design concentration.
(2) Extinguishment times are measured from the beginning of agent discharge.
(3) After agent discharge, the oxygen concentration is relatively uniform throughout the compartment.

**Table 15. Fire Scenario 3A – Test Results**

| Agent | NAF-SIII | CEA-410 | FM-200 |
|---|---|---|---|
| Agent Concentration (%) | 12 | 8.2 | 8.7 |
| Relative Concentration(1) | 1.2 | 1.4 | 1.3 |
| Number of Nozzles | 2 | 4 | 4 |
| Nozzle | N1 | N6 | N7 |
| Discharge Time (s) | 10.5 | 10 | 10 |
| Wood Crib Mass Loss (%) | 40 | 41 | 39 |
| Extinguishment Time(s)(2) Wood crib (deck) | 9 | 8 | 7 |
| Extinguishment Time(s)(2) Heptane pan fire (side) | 15 | 13 | 9 |
| Extinguishment Time(s)(2) Heptane pan fire (bilge) | 12 | 13 | 15 |
| Extinguishment Time(s)(2) Heptane spray fire (top) | 1 | 1 | 2 |
| Agent Concentration (%), 5:00 Average | 12.3 | 8.7 | 8.7 |
| HF Concentration (ppm), 5:00 Average | 5100 | 4300 | 5000 |
| Positive Compartment Pressure (kPa) | 0.5 | 0 | 0.5 |
| Negative Compartment Pressure (kPa) | 2.5 | 3.8 | 2.8 |
| Oxygen Conc. after Discharge (%)(3) | 15.8 | 17.5 | 17.0 |

Note: (1) Relative concentrations are based on the telltale design concentration.
(2) Extinguishment times are measured from the beginning of agent discharge.
(3) After agent discharge, the oxygen concentration is relatively uniform throughout the compartment.

**Table 16. Fire Scenario 3B – Test Results**

| Agent | NAF-SIII | CEA-410 | Halon | FM-200 | Envirogel | NAF-SIII |
|---|---|---|---|---|---|---|
| Agent Concentration (%) | 12 | 8.2 | 5 | 8.7 | 4.6 | 12 |
| Relative Concentration(1) | 1.2 | 1.4 | 1.6 | 1.3 | .5 | 1.2 |
| Number of Nozzles | 2 | 4 | 2 | 4 | 2 | 2 |
| Nozzle | N1 | N6 | N4 | N7 | N9 | N5 |
| Discharge Time (s) | 9.5 | 10 | 9.5 | 10 | ? | 9 |
| Wood Crib Mass Loss (%) | 38 | 43 | 40 | 44 | 44 | 42 |
| Extinguishment Time(s)(2) Wood crib (deck) | 7 | 8 | 5 | 3 | 10 | 4 |
| Extinguishment Time(s)(2) Diesel pan fire (bilge plate) | 8 | 8 | 10 | 11 | 10 | 4 |
| Extinguishment Time(s)(2) Heptane spray fire (side) | 14 | 9 | 11 | 9 | 180* | 4 |
| Agent Concentration (%), 5:00 Average | 10.8 | 7.7 | 4.8 | 8.1 | 5.0 | 11.6 |
| HF Concentration (ppm), 5:00 Average | 2300 | 2600 | 300 | 3900 | 5800 | 3400 |
| Positive Compartment Pressure (kPa) | 1.0 | 0.5 | 0 | 0.5 | 0.25 | 0.37 |
| Negative Compartment Pressure (kPa) | >1.25 | 3.0 | 0 | 2.0 | 3.0 | 3.0 |
| Oxygen Conc. after Discharge (%)(3) | 15.3 | 16.7 | 17.3 | 16.3 | 18.3 | 14.3 |

Note: (1) Relative concentrations are based on the telltale design concentration.
(2) Extinguishment times are measured from the beginning of agent discharge.
(3) After agent discharge, the oxygen concentration is relatively uniform throughout the compartment.
* Fire appeared to extinguish due to oxygen depletion.

Consistent with the spray fires in Fire Scenario 2, the proposed heptane spray fire located on top of the mockup was blown out during these tests. This is illustrated by the 1-2 second extinguishment times listed in Table 15. However, the heptane spray fire on the side of the mockup was adequately shielded to prevent the fire(s) from being blown out and provided a challenge for the agents evaluation in this investigation. These shielded heptane spray fires were typically extinguished between 10-15 seconds of the beginning of agent discharge.

It was difficult to determine the extinguishment times for the wood crib fires. The times shown on Tables 14, 15, and 16 were based on visual observations. The 30 cm x 30 cm x 30 cm wood cribs used during Fire Scenarios 3A and 3B ignited and sustained burning better than the 45 cm x 45 cm x 20 cm crib specified in the test protocol (Fire Scenario 3). The extinguishment times and total mass loss of the wood cribs were consistent with respect to the type of crib. The 30 cm x 30 cm x 30 cm wood crib was typically extinguished in 10 seconds and experienced a 40-45 percent mass loss as compared to an extinguishment time of 5 seconds and a 20-25 percent mass loss for the 45 cm x 45 cm x 20 cm wood crib. The size of the heptane pan and the height of the wood crib should also be re-evaluated. The size of the heptane pan should be reduced, and the crib should be located approximately 5-10 cm above the pan.

On a final note, the extinguishment times recorded during the various versions of Fire Scenario 3 appear to get longer with decreased fire size. However, the majority of this variation is attributed to changes in the component fires (i.e., fire location and type) rather than the total heat release of the fire scenario.

### 9.4.4 Fire Scenario 4

The test results for Fire Scenarios 4 (6.0 MW) and 4A (4.75 MW) are shown in Tables 17 and 18, respectively. Generally speaking, the pan fires located in the bilge area for both fire scenarios provided a significant challenge for the agents evaluated during this

investigation. The extinguishment times for these fires ranged from 8-15 seconds independent of the size of the fire and the type of fuel. The large diesel fuel pan fire in Scenario 4 appeared to reduce in size halfway into the two-minute preburn. This was confirmed by placing an oxygen probe in the bilge area during one of the tests. During the preburn, the oxygen concentration in the bilge dropped below 15 percent prior to agent discharge. The oxygen concentration elsewhere in the space was typically on an average of 2-3 percent higher than that in the bilge. This suggests, as discussed in the freeburn section of this report, that the openings into the bilge area are inadequate to support the combustion of a 6.0 MW fire. The low concentrations of HF produced during these tests also supports this conclusion. The concentrations of HF produced during these tests are roughly half the value expected from a 6.0 MW fire and were discussed in previous sections (9.3.2 and 9.3.5) of this report.

**Table 17. Fire Scenario 4 – Test Results**

| Agent | NAF-SIII | Halon | CEA-410 | FM-200 | NAF-SIII |
|---|---|---|---|---|---|
| Agent Concentration (%) | 12 | 5 | 8.2 | 8.7 | 12 |
| Relative Concentration(1) | 1.2 | 1.6 | 1.4 | 1.3 | 1.2 |
| Number of Nozzles | 2 | 2 | 4 | 4 | 2 |
| Nozzle | N1 | N4 | N6 | N7 | N5 |
| Discharge Time (s) | 9.5 | 9 | 10 | 10 | 9 |
| Extinguishment Time(s)(2) Diesel pan fire (bilge) | 10 | 10 | 12 | 15 | 9 |
| Agent Conc. (%), 5:00 Average | 11.8 | 4.7 | 8.7 | 8.8 | 10.2 |
| HF Conc. (ppm), 5:00 Average | 1000 | 400 | 1400 | 2400 | 9000 |
| Positive Compartment Pressure (kPa) | 0.37 | 0.5 | 0.75 | 0.25 | 0.25 |
| Negative Compartment Pressure (kPa) | >1.25 | 1.5 | 6.25 | 2.25 | 2.5 |
| Oxygen Conc. after Discharge (%)(3) | 15.1 | 17.0 | 15.0 | 16.0 | 14.0 |

Note: (1) Relative concentrations are based on the telltale design concentration.
(2) Extinguishment times are measured from the beginning of agent discharge.
(3) After agent discharge, the oxygen concentration is relatively uniform throughout the compartment.

**Table 18. Fire Scenario 4A Extinguishment Summary**

| Agent | NAF-SIII | CEA-410 | FM-200 |
|---|---|---|---|
| Agent Concentration (%) | 12 | 8.2 | 8.7 |
| Relative Concentration(1) | 1.2 | 1.4 | 1.3 |
| Number of Nozzles | 2 | 4 | 4 |
| Nozzle | N1 | N6 | N7 |
| Discharge Time (s) | 10.5 | 10 | 10 |
| Extinguishment Time(s)(2) Heptane pan fire (bilge) | 11 | 8 | 12 |
| Extinguishment Time(s)(2) Diesel pan fire (bilge) | 11 | 9 | 14 |
| Extinguishment Time(s)(2) Heptane spray fire (top) | 2 | 1 | 2 |
| Agent Conc. (%), 5:00 Average | 12.3 | 7.9 | 8.7 |
| HF conc. (ppm), 5:00 Average | 1900 | 4500 | 3700 |
| Positive Compartment Pressure (kPa) | 0.25 | 0.25 | 0.5 |
| Negative Compartment Pressure (kPa) | 2.75 | 3.5 | 3.0 |
| Oxygen Conc. after Discharge (%)(3) | 13.0 | 13.8 | 14.5 |

Note: (1) Relative concentrations are based on the telltale design concentration.
(2) Extinguishment times are measured from the beginning of agent discharge.
(3) After agent discharge, the oxygen concentration is relatively uniform throughout the compartment.

Based on the area of the pans and the heat of combustion of the fuels, the total heat release rate (fire size) of Fire Scenario 4A should be less than Fire Scenario 4. However, the amount of oxygen depletion observed in the space and the quantity of HF produced during the extinguishment of these fires suggest that Fire Scenario 4A was larger than Fire Scenario 4. Two small pan fires located near the edges of the bilge in Fire Scenario 4A must produce better air entrainment into the bilge than the large pan fire in the center of the bilge in Fire Scenario 4. The HF produced during extinguishment of both Scenario 4 and 4A suggests that the bilge fires in both scenarios were smaller than expected due to localized oxygen depletion effects.

### 9.4.5 Fire Scenario Summary

The extinguishment times observed for the halocarbon agents evaluated during these tests were comparable to those observed for Halon 1301. All of the fires were extinguished prior to or shortly after agent discharge (less than 15 seconds), with many of them extinguished almost instantly. While it was originally thought that the oxygen depletion resulting from these large fires would make these fires relatively easy to extinguish, the data do not support this conclusion. The data shows little, if any, variation in the extinguishment times between the candidate agents and/or the size of the fire. While the oxygen depletion did not appear to affect the results of this evaluation, the fires would have, however, self-extinguished prior to the two-minute discharge time allowed when evaluating an inert gas. Consequently, the test protocol requires modification in order to evaluate the performance of an inert gas or other agents with long discharge times (>15-20 seconds).

The very rapid extinguishment of the unobstructed fires illustrates the importance of minimizing the effects of flow turbulence and transient, locally high agent concentrations in the extinguishment process. In general, total flooding gaseous extinguishing systems must extinguish fires under the assumptions of low flow turbulence in the vicinity of the flame and uniform (design) concentrations throughout the space.

## 10.0 SUMMARY

### 10.1 IMO Test Protocol

1. The proposed IMO test protocol and modifications tested in this evaluation indicate that the protocol provides a reasonable basis for evaluating total flooding gaseous agents and nozzle design parameters. There are, however, a number of areas that could be improved.

2. The proposed test procedure should be limited as follows:

   a. The protocol should only apply to total flooding gases and should not be used as the only basis of evaluating agents containing solid or liquid aerosols.

   b. The procedure requires modification if it is to be used with systems that have discharge times greater than 15 seconds. This can be accomplished with smaller fires and subsequent reduced oxygen depletion.

   c. The average nozzle pressure, maximum discharge time, and maximum nozzle spacing used in the telltale fire tests should form the design limits used in installations.

   d. Since there is no long duration reignition test or hot surfaces which retain sufficient energy to form a long duration ignition source, a minimum acceptable agent hold time should be required in the design and installation standard.

3. Proposed improvement and areas of the test procedure that this evaluation indicate may benefit from further study are outlined below:

   a. Modify the protocol to evaluate alternative nozzle designs, spacing, maximum discharge time, and minimum nozzle pressure once the agent has been tested against all of the scenarios. This could include telltale fires only, a subset of large fires, or all of the fire tests specified.

   b. Add tests with smaller fires to establish the role of oxygen depletion on extinguishment.

c. Add telltale fires, particularly in the bilge area.

d. Modify the test protocol to include an energetic long duration reignition source (i.e., spark or electrical resistance heater).

e. Obstruct, baffle, or relocate the spray fires located on top of the engine mockup.

f. Minimize oxygen depletion during preburn by increasing ventilation opening sizes or by adding forced mechanical ventilation.

g. Increase the ventilation openings into the bilge to minimize localized oxygen depletion during the bilge fire tests (i.e., lowering the baffle height or opening one side of the bilge).

h. Specify the fuel quantity required to ignite the wood crib.

i. Modify the wood crib size to improve its burning characteristics, perhaps to a 30 cm cube, versus the 45 cm x 45 cm x 20 cm crib currently required.

j. Reduce the height the wood crib is installed above the heptane pan used to ignite the crib.

4. Proposed improvement and areas of the test procedure not specifically tested in this evaluation that may benefit from further study are outlined below.

a. Evaluate system performance with cylinders conditioned to the lowest design temperature.

b. Clarification is needed in paragraph 3.3.2.2 of the protocol to identify that the Test 1 exception is only for a new nozzle or related hardware for a previously tested fire extinguishant system and not for a previously tested fire extinguishant.

## 10.2 Observations While Performing the Protocol

Three agents (CEA-410, FM-200, and NAF-SIII) completed the draft IMO test protocol for gaseous agents. These three agents were capable of extinguishing all of the fires in this investigation. The extinguishment time observed during these tests follow similar trends found throughout the literature. Extinguishment times were found to be a function of both discharge time and design concentration. Due to the similarity in design parameters used by each manufacturer, the extinguishment times observed during these tests were similar between agents and fire size. During these tests the unobstructed fires were rapidly extinguished in a few seconds (2-5 seconds) while the shielded and obstructed fires were extinguished near the end of agent discharge (10-15 seconds).

The compartment pressures measured during these tests followed the same trends found throughout the literature. The pressure histories were observed to have both a positive and negative component with the negative component occurring first due to the rapid cooling of the gases in the space followed by the positive component resulting from the additional mass (agent) added to the compartment. The magnitude of negative pressure component was typically many times that of the positive component and was measured as high as –6.9 kPa. This can be attributed in part to the pressure relieving design of the 6 $m^2$ exhaust damper. The damper was only held closed by gravity and therefore allowed to lift due to positive pressure. These variations in compartment pressure may need to be considered when designing gaseous agent systems based on the construction and strength of the compartment.

The HF concentrations measured during these tests also followed the same trends identified in other studies. The HF produced by the halocarbon agents was measured to be 5-10 times that of Halon 1301. For relatively quick extinguishment times (around 10 seconds), the HF production appears to be approximately linear and a function of the ratio of fire size to compartment volume.

In conjunction with previous testing [6], extinguishment time was determined to be a primary factory in HF production. For a properly designed system utilizing adequate agent concentrations (1.2 to 1.3 times the cup burner number), extinguishment should occur at approximately the end of agent discharge. Extinguishment times can be reduced through good discharge system and nozzle design as well as adequate design concentrations. Discharge systems and nozzles need to be designed to produce and distribute an adequate agent concentration uniformly throughout the space as quickly as possible to increase the likelihood for a rapid extinguishment. Early detection and activation of the system while the fire is relatively small would also have substantial effects.

The hazard posed by the concentrations of HF produced during the extinguishment of large hydrocarbon pool and spray fires must be evaluated in the context of the hazard posed by an unmitigated fire. For personnel located in the space during a fire event of the magnitude of these scenarios, the hazard posed by the HF may be no worse than that posed by the fire. Additional precautions may be required for personnel entering the space after fire extinguishment has occurred.

## 11.0 REFERENCES

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4. United States Coast Guard, "Sub-Committee on Fire Protection 41st Session, Agenda Item 8.2., Recommendations for the Evaluation of Fire Fighting Systems," July 1996.

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# Appendix A

# IMO Test Protocol and Recommended Changes

IMO



SUB-COMMITTEE ON FIRE PROTECTION - 40th session
Agenda item 5

# FIRE FIGHTING SYSTEMS

## Report of the Working Group

1 Attached are annexes 5 and 6 with reference to paragraph 12 of the working group's report FP 40/WP.9:

Annex 5 Draft guidelines for the approval of fixed gas fire-extinguishing system for machinery spaces and cargo pump-rooms.

Annex 6 Draft test method for fixed gas fire-extinguishing system for machinery spaces and cargo pump-rooms.

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## ANNEX 5

## DRAFT GUIDELINES FOR THE APPROVAL OF EQUIVALENT FIXED GAS FIRE-EXTINGUISHING SYSTEMS AS REFERRED TO IN SOLAS 74 FOR MACHINERY SPACES AND CARGO PUMP-ROOMS

### General

1 Fixed gas fire-extinguishing systems for use in machinery spaces of category A and cargo pump-rooms equivalent to fire-extinguishing systems required by SOLAS regulations II-2/7 and II-2/63 should prove that they have the same reliability which has been identified as significant for the performance of fixed gas fire-extinguishing systems approved under the requirements of SOLAS regulation II-2/5. In addition the system should be shown by test to have the capability of extinguishing a variety of fires that can occur in a ship's engine-room.

### Principal Requirements

2 All requirements of Regulation 5 section 1 and section 3, except as modified by these guidelines, should apply.

3 The minimum extinguishing concentration should be determined by a cup burner test apparatus. The design concentration should be at least 20 percent above the minimum extinguishing concentration. These concentrations should be verified by full-scale testing described in the test method, as set down in annex 6.

4 For systems using halocarbon clean agents, 95 percent of the design concentration should be discharged in 10 seconds. For inert gas systems, the discharge time should not exceed 120 seconds for 85 per cent of the design concentration.

5 The quantity of extinguishing agent for the protected space should be calculated using the design concentration based on the gross volume of the protected space including the casing. If the quantity of extinguishing agent when applied to the net volume of the protected space including casing exceeds the agent's LOAEL (Lowest Observed Adverse Effect Level), the quantity of agent should be reduced, but not below the agent's design concentration based on net volume.

6 No fire suppression agent should be used which is carcinogenic, mutagenic, or teratogenic. No agent should be used in concentrations greater than the cardiac sensitization NOAEL (No Observed Adverse Effect Level), or the ALC (Approximate Lethal Concentration), without the use of controls as set down in SOLAS 74 regulation II-2/5.2.5.1 and 5.2.5.2. In no case should an agent be used above its LOAEL (Lowest Observed Adverse Effect Level).

7 The system and its components should be suitably designed to withstand ambient temperature changes, vibration, humidity, shock, impact, clogging, and corrosion normally encountered in machinery spaces or cargo pump-rooms in ships.

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1 Until International Standards are developed, acceptable national standards should be used. Such standards include Standards Australia, United Kingdom and NFPA 2001.

8 The system and its components should be designed and installed in accordance with international standards acceptable to the Organization[1] and manufactured and tested to the satisfaction of the Administration in accordance with appropriate elements of the proposed test procedure. As a minimum, the design and installation standards should cover the following elements:

.1 safety

toxicity
noise, nozzle discharge
decomposition products;

.2 storage container design and arrangement

strength requirements
maximum/minimum fill density, operating temperature range
pressure and weight indication
pressure relief
agent identification and lethal requirements;

.3 agent supply, quantity, quality standards;

.4 pipe and fittings

strength, material, properties, fire resistance,
cleaning requirements;

.5 valves

testing requirements
corrosion resistance
elastomer compatibility;

.6 nozzles

height and area testing requirements
corrosion and elevated temperature resistance;

.7 actuation and control systems

testing requirements
backup power requirements;

.8 alarms and indicators

predischarge alarm, agent discharge alarms as time delays
abort switches
supervisory circuit requirements
warning signs;

.9 agent flow calculation

approval and testing of design calculation method
fitting losses and/or equivalent length;

.10 enclosure integrity and leakage requirements

enclosure leakage
unenclosable openings
mechanical ventilation interlocks;

.11 design concentration requirements, total flooding quantity;

.12 discharge time;

.13 inspection, maintenance, and testing requirements.

9 The nozzle location, type of nozzle, nozzle spacing and height and minimum nozzle pressure should be within the limits tested to provide fire extinction as per the proposed test method.

10 Provisions should be made to ensure that escape routes which are exposed to leakage from the protected space are not rendered hazardous during or after discharge of the agent.

11 The arrangement of containers and electrical circuits and piping essential for the release of any system should be such that in the event of damage to any one power release line through fire or explosion in the protected space, i.e., a single fault concept, at least five sixth of the fire-extinguishing charge [required by paragraphs SOLAS regulation II-2/5. 5.3.2.9 or 3.2.10 for that space] can still be discharged having regard to the requirement for uniform distribution of medium throughout the space. The arrangements in respect of systems for spaces requiring less than 6 containers should be to the satisfaction of the Administration.

***

## ANNEX 6

# DRAFT TEST METHOD FOR FIRE TESTING OF FIXED GAS FIRE-EXTINGUISHING SYSTEMS AS REFERRED TO IN SOLAS 74 FOR MACHINERY SPACES AND CARGO PUMP-ROOMS

## 1 Scope

1.1 This test method is intended for evaluating the extinguishing effectiveness of fixed gas fire-extinguishing systems for the protection of machinery spaces of category A and cargo pump-rooms.

1.2 Fire-extinguishing systems presently covered in chapter II-2, regulation 5 of SOLAS 1974, as amended, are excluded.

1.3 The test method covers the minimum requirements for fire-extinguishing and prevention against re-ignition.

## 2 Sampling

The components to be tested should be supplied by the manufacturer together with design and installation criteria, operational instructions, drawings and technical data sufficient for the identification of the components.

## 3 Method of test

3.1 Principle

This test procedure enables the determination of the effectiveness of different gaseous agent extinguishing systems against spray fires, pool fires and class A fires.

3.2 Apparatus

3.2.1 Test room

The tests should be performed in 100 $m^2$ room with no dimension less than 8 m, with a ceiling height of 5 m. The test room should be provided with a closable access door measuring approximately 4 $m^2$ in area. In addition, closable ventilation hatches measuring at least 6 $m^2$ in total area should be located in the ceiling.

3.2.2 Integrity of test enclosure.

The test enclosure is to be nominally leak tight when doors and hatches are closed. The integrity of seals on doors, hatches, and other penetrations (e.g., instrumentation access ports) must be verified before each test.

3.2.3 Engine mock-up

.1 An engine mock-up of size (width x length x height) 1 m x 3 m x 3 m should be constructed of sheet steel with a nominal thickness of 5 mm. The mock-up should be fitted with two steel tubes diameter 0.3 m and 3 m length that simulate exhaust manifolds and a solid steel plate. At the top of the mock-up a 3 $m^2$ tray should be arranged. See Figures 1, 2 and 3.

.2 A floor plate system 4 m x 6 m x 0.75 m high surrounding the mock-up with three trays, 2, 2, and 4 $m^2$, equalling a total area of 8 $m^2$, underneath, should be as in Figures 1, 2 and 3.

3.2.4 Instrumentation

Instrumentation for the continuous measurement and recording of test conditions should be employed. The following measurements should be made:

.1 temperature at three vertical positions (e.g., 1, 2.5, and 4.5 m)

.2 enclosure pressure

.3 gas sampling and analysis, at mid-room height, for oxygen, carbon dioxide, carbon monoxide, and relevant halogen acid products

.4 means of determining flame-out indicators

.5 fuel nozzle pressure in the case of spray fire

.6 fuel flow rate in the case of spray fires

3.2.5 Nozzles

3.2.5.1 Nozzles should be located within 1 m of the ceiling

3.2.5.2 If more than one nozzle is used they should be symmetrically located.

3.3 Test fires & programme

3.3.1 Fire types

The test programme, as described in Table 2, should employ test fires as described in Table 1.

Table 1
Parameters of Test Fires

| Fire | Type | Fuel | Fire Size, MW | Remarks |
|---|---|---|---|---|
| A | 76 - 100 mm ID Can | Heptane | 0.0012 to 0.002 | Tell tale |
| B | 0.25 $m^2$ Tray | Heptane | 0.35 | |
| C | 2 $m^2$ Tray | Diesel /Fuel Oil | 3 | |
| D | 4 $m^2$ Tray | Diesel /Fuel Oil | 6 | |
| E | Low pressure spray | Heptane 0.16 ± 0.01 kg/s | 5.8 | |
| F | Low pressure, low flow spray | Heptane 0.03 ± 0.005 kg/s | 1.1 | |
| G | High pressure spray | Diesel /Fuel Oil 0.05 ± 0.002 kg/s | 1.8 | |
| H | Wood Crib | Spruce or Fir | 0.3 | See Note 2 |

Notes to Table 1:

1 Diesel /Fuel Oil means light diesel or commercial fuel oil.

2 The wood crib should be substantially the same as described in ISO/TC 21/SC5/WG 8 ISO Draft International Standard , *Gaseous fire extinguishing systems, Part 1: General Requirements*. The crib should consist of six, trade size 50 mm x 50 mm by 450 mm long, kiln dried spruce or fir lumber having a moisture content between 9 and 13 percent. The members should be placed in 4 alternate layers at right angles to one another. Members should be evenly spaced forming a square structure.

Achieve ignition of the crib by burning commercial grade heptane in a square steel tray 0.25 $m^2$ in area. During the pre-burn period the crib should be placed centrally above the top of the tray a distance of 300 to 600 mm.

Oil spray fire test parameters

| Fire type | Low pressure | Low pressure, Low flow | High pressure |
|---|---|---|---|
| Spray nozzle | Wide spray angle (120 to 125°) full cone type | Wide spray angle (80°) full cone type | Standard angle (at 6 Bar) full cone type |
| Nominal oil pressure | 8 Bar | 8.5 Bar | 150 Bar |
| Oil flow | 0.16 ± 0.01 kg/s | 0.03 ± 0.005 kg/s | 0.050 ± 0.002 kg/s |
| Oil temperature | 20 ± 5°C | 20 ± 5°C | 20 ± 5°C |
| Nominal heat release rate | 5.8 ± 0.6 MW | 1.1 ± 0.1 MW | 1.8 ± 0.2 MW |

3.3.2 Test programme

The fire test programme should employ test fires singly or in combination, as outlined in Table 2.

Table 2
Test Programme

| Test No. | Fire Combinations (See Table 1) |
|---|---|
| 1 | A: Tell tales, 8 corners. See note 1. |
| 2 | B: 0.25 m2 heptane tray under engine mockup<br>F: Horizontal LP spray directed at 15-25 mm rod 0.5 m away<br>G: HP spray on top of simulated engine<br><br>Total Fire load: 7.95 MW |
| 3 | C: 2 $m^2$ tray positioned 0.75 m above floor<br>H: Wood crib positioned 0.75 m above floor.<br>E: Low pressure, low flow horizontal spray - concealed - with oil impingement on inside of engine mock-up wall.<br><br>Total Fire load: 4.3 MW |
| 4 | D: 4 $m^2$ Diesel tray under simulated engine.<br><br>Total Fire Load: 6 MW |

Note to Table 2: Telltale fire cans should be located as follows:

(a) in upper corners of enclosure 150 mm below ceiling and 50 mm from each wall;
(b) in corners on floors 50 mm from walls

3.4 Extinguishing system

3.4.1 System installation

The extinguishing system should be installed according to the manufacturer's design and installation instructions. The maximum vertical distance should be limited to 5 m.

3.4.2 Agent

3.4.2.1 Design concentration

The agent design concentration is that concentration (in volume per cent) required by system designer for the fire protection application.

3.4.2.2 Test concentration

The concentration of agent to be used in the fire extinguishing tests should be the design concentration specified by the system manufacturer, except for test 1 which would be conducted at the minimum extinguishing concentration.

3.4.2.3 Quantity of agent

The quantity of agent to be used should be determined as follows:

3.4.2.3.1 Halogenated agents

$W = (V/S) \cdot C/(100 - C)$ where

W = agent mass, kg
V = volume of test enclosure, $m^3$
S = agent vapor specific volume at temperature and pressure of the test enclosure, $kg/m^3$
C = gaseous agent concentration, volume per cent

3.4.2.3.2 Inert gas agents

$Q = V\,[294/(273 + T)] \cdot (P/1.013) \cdot \ln[100/(100 - C)]$ where

Q = volume of inert gas, measured at 294 K and 1.013 bar, discharged, $m^3$
V = volume of test enclosure, $m^3$
T = test enclosure temperature, Celcius
P = test enclosure pressure, bar
C = gaseous agent concentration, volume per cent
(Reference NFPA 2001: 1994)

3.5 Procedure

3.5.1 Fuel levels in trays

The tray/s used in the test should be filled with at least 30 mm fuel on a water base. Freeboard should be 150 ± 10 mm

3.5.2 Fuel flow and pressure measurements

For spray fires the fuel flow and pressure in the oil system should be measured before and during each test.

3.5.3 Ventilation

3.5.3.1 Pre-burn period

During the pre-burn period the test enclosure should be well ventilated.

3.5.3.2 End of pre-burn period

Doors, ceiling hatches, and other ventilation openings should be closed at the end of the pre-burn period.

3.5.4 Duration of test

3.5.4.1 Pre-burn time

Fires should be ignited such that the following burning times occur before the start of agent discharge:

| | | |
|---|---|---|
| .1 | sprays - | 5 to 15 seconds |
| .2 | trays - | 2 minutes |
| .3 | crib - | 6 minutes |

3.5.4.2 Discharge time

.1 halogenated agents should be discharged at a rate sufficient to achieve delivery of 95% of the minimum design quantity in 10 seconds or less.

.2 inert gas agents should be discharged at a rate sufficient to achieve 85% of the minimum design quantity in 120 seconds or less.

3.5.4.3 Soak time

After the end of agent discharge the test enclosure should be kept closed for 15 minutes.

3.5.5 Measurements and observations

3.5.5.1 Before test

.1 temperature of test enclosure, fuel and engine mock-up
.2 initial weights of agent containers
.3 verification of integrity agent distribution system and nozzles
.4 initial weight of wood crib

3.5.5.2 During test

.1 start of the ignition procedure
.2 start of the test (ignition)
.3 time when ventilating openings are closed
.4 time when the extinguishing system is activated
.5 time from end of agent discharge
.6 time when the oil flow for the spray fire is shut off
.7 time when all fires are extinguished
.8 time of re-ignition, if any, during soak period
.9 time at end of soak period at which point doors should be opened enclosure vented
.10 at the start of test initiate continuous monitoring as per 3.2.4.3

3.5.6 Tolerances

Unless otherwise stated, the following tolerances should apply:

| | | |
|---|---|---|
| .1 | Length | ±2% of value |
| .2 | Volume | ±5% of value |
| .3 | Pressure | ±3% of value |
| .4 | Temperature | ±5% of value |

These tolerances are in accordance with ISO standard 6182/1, February 1994 edition [4].

## 4 Classification criteria

4.1 Class B fires must be extinguished within 30 seconds of the end of agent discharge. At the end of the soak period there should be no re-ignition upon opening the enclosure.

4.2 The oil spray should be shut off 15 seconds after extinguishment. At the end of the soak time, the oil spray should be restarted for 15 seconds prior to reopening the door and there should be no reignition.

4.3 At the end of the test fuel trays must contain sufficient fuel to cover the bottom of the tray.

4.4 Wood crib weight loss must be no more than 60%.

## 5 Test report

The test report should include the following information:

.1 Name and address of the test laboratory
.2 Date and identification number of the test report
.3 Name and address of client
.4 Purpose of the test
.5 Method of sampling system components

.6 Name and address of manufacturer or supplier of the product
.7 Name or other identification marks of the product
.8 Description of the tested product
- drawings
- descriptions
- assembly instructions
- specification of included materials
- detailed drawing of test set-up

.9 Date of supply of the product
.10 Date of test
.11 Test method
.12 Drawing of each test configuration
.13 Identification of the test equipment and used instruments
.14 Conclusions
.15 Deviations from the test method, if any
.16 Test results including observations during and after the test; and
.17 Date and signature.

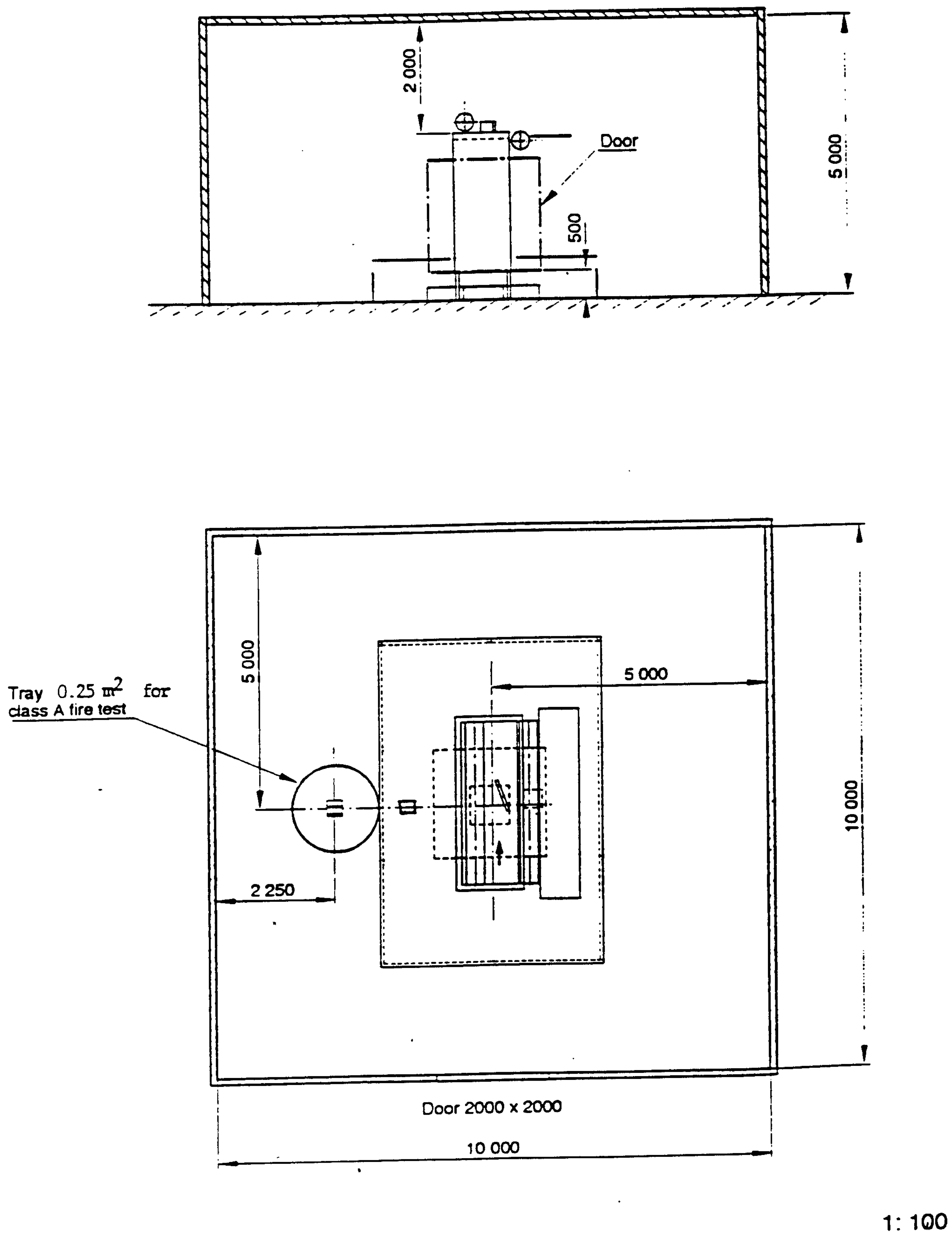

2 000
Door
500
5 000
5 000
5 000
Tray 0.25 m2 for class A fire test
10 000
2 250
Door 2000 x 2000
10 000
1: 100

Figure 1

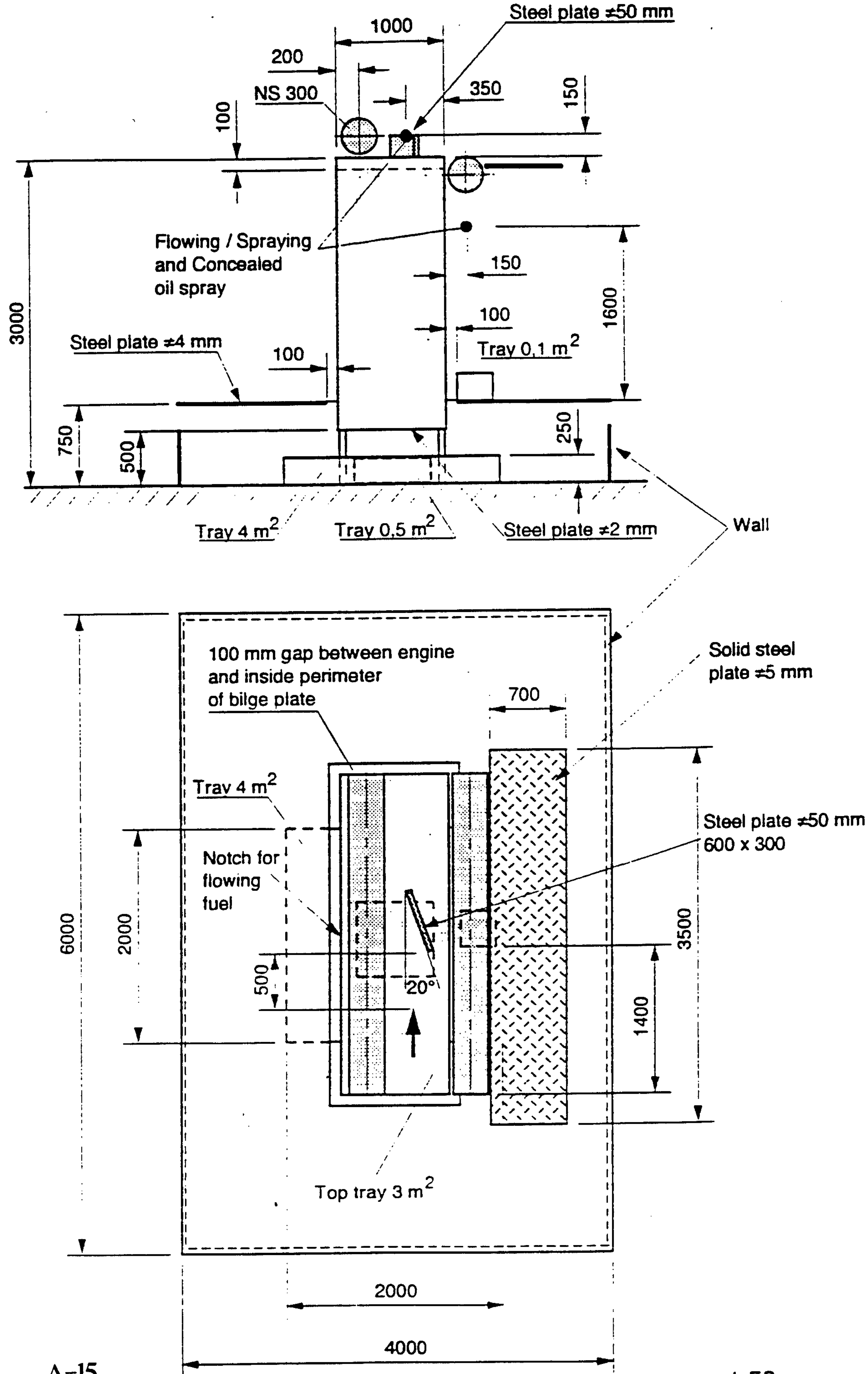
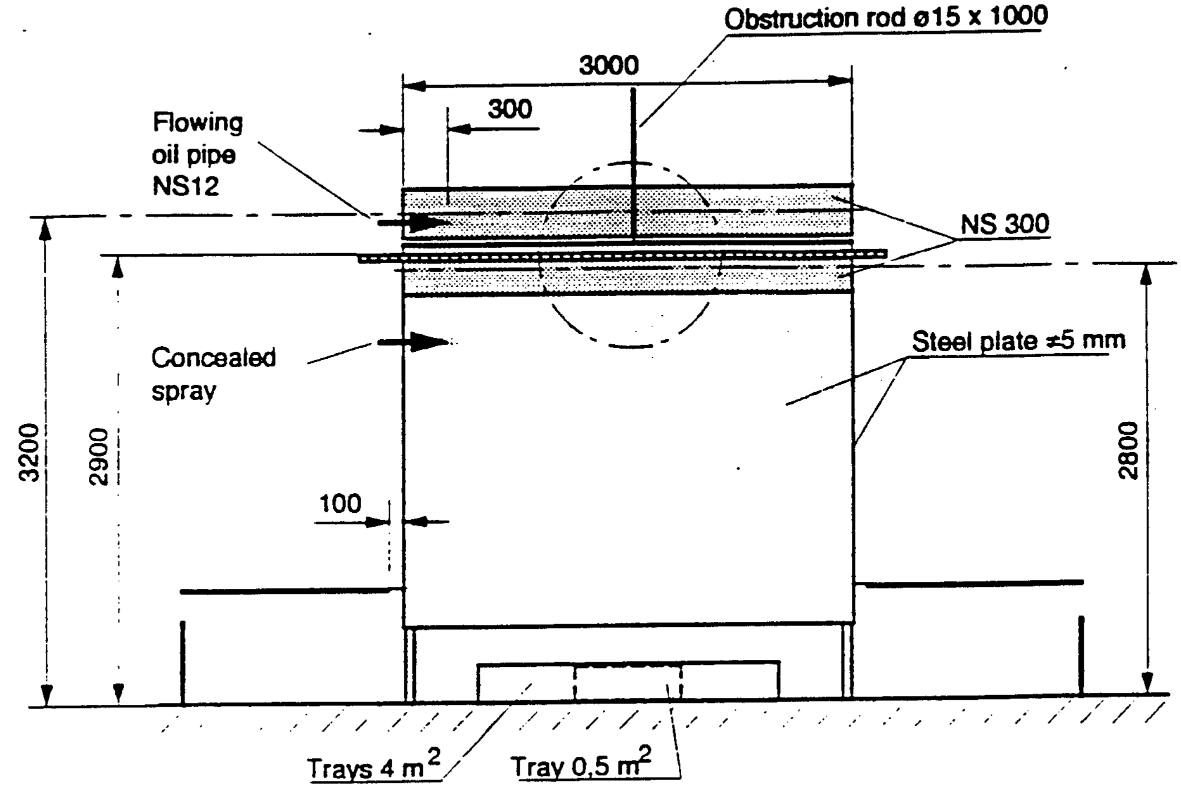

1000
200
NS 300
Steel plate ±50 mm
350
150
100
3000
Flowing / Spraying
and Concealed
oil spray
150
100
1600
Steel plate ±4 mm
100
Tray 0,1 m2
750
500
250
Tray 4 m2
Tray 0,5 m2
Steel plate ±2 mm
Wall
100 mm gap between engine
and inside perimeter
of bilge plate
Solid steel
plate ±5 mm
700
Trav 4 m2
Notch for
flowing
fuel
Steel plate ±50 mm
600 x 300
6000
2000
500
20°
3500
1400
Top tray 3 m2
2000
4000
1:50



Figure 2


Obstruction rod ø15 x 1000
3000
300
Flowing
oil pipe
NS12
NS 300
Concealed
spray
Steel plate ±5 mm
3200
2900
100
2800
Trays 4 m²
Tray 0,5 m²

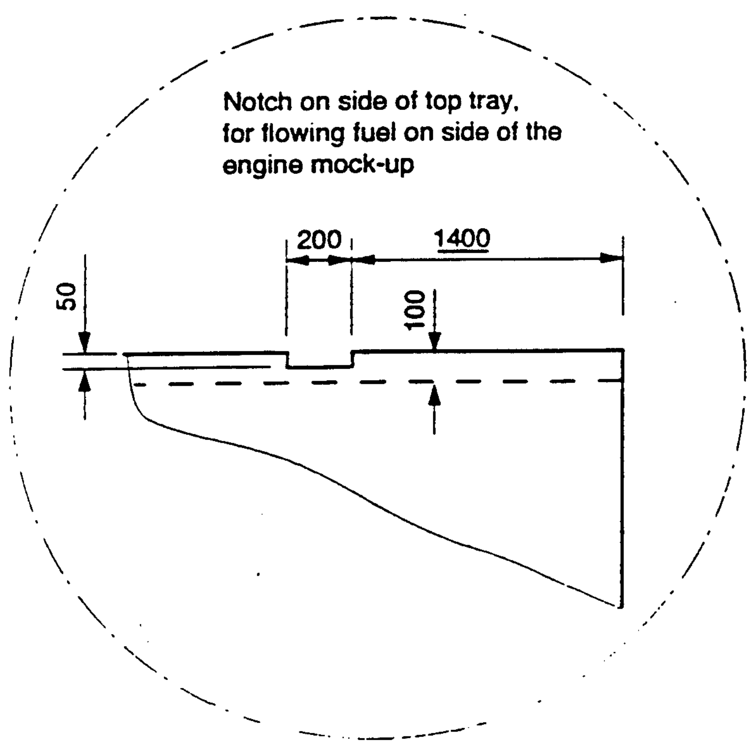

Notch on side of top tray,
for flowing fuel on side of the
engine mock-up
200
1400
50
100

Figure 3



1:50

INTERNATIONAL MARITIME
ORGANIZATION

IMO

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5 July 1996
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SUB-COMMITTEE ON FIRE PROTECTION
41st session
Agenda item 8.2

## FIRE-FIGHTING SYSTEMS

### Fire-fighting Systems in Machinery and Other Spaces

**Submitted by the United States**

1 At the fortieth session of the Sub-Committee on Fire Protection a draft test method was developed for gaseous halon alternatives. The United States has an ongoing research program to evaluate the draft test method in a compartment aboard the test vessel State of Maine. The program will include several gaseous extinguishing agents and is expected to run through August 1996. The United States will bring to the forty-first session of the sub-committee information regarding the validity of the draft test procedures. A proposed revised test procedure is provided in the annex.

2 In MSC 64/7, the United States recommended updating the requirements of SOLAS to reflect new technologies and to reflect the current body of knowledge regarding machinery space fire protection. The need for improved, updated, machinery space fire protection practices continues to exist as reflected by an IMO appointed panel of experts evaluating ro-ro ferry safety following the Estonia disaster. The panel of experts recommended the provision of local fire extinguishing systems to protect combustion machinery on ro-ro ferries as a supplement to total flooding machinery space protection. The United States strongly supports the provision of automatic, water based, local or zoned fire suppression systems in machinery spaces to supplement total space protection. The ability of a fire suppression system to absorb heat, wash smoke and reduce flame volume is seen as critical to the success of the firefighting effort. In addition, recent testing by the US Navy shows that gaseous fire extinguishing systems work well when coupled with water sprays or mists, especially when the water is applied before the gas is released. Some of the tests included in MSC/Circ 668, such as the large fires in the class 3 engine rooms, and certain tests developed in Europe for protection of car decks appear to be appropriate for evaluating local protection systems. Locally applied water mists and sprays will not stop a ship's propulsion engine from operating and advancements in fusible bulb technology allow for the design of automatic local systems which are not subject to false activation.

**Action requested of the Sub-Committee**

3 The Sub-Committee is invited to develop guidelines for the implementation of local, zoned water based fire suppression systems for protection of main and auxiliary machinery and to finalize the test procedures for gaseous alternatives to halon.

***

# ANNEX 1

## TEST METHOD FOR FIRE TESTING OF FIXED GAS FIRE EXTINGUISHING SYSTEMS

### 1 Scope

1.1 This test method is intended for evaluating the extinguishing effectiveness of fixed gas fire extinguishing systems for the protection of machinery spaces of category A and cargo pump rooms.

1.2 Fire extinguishing systems presently covered in chapter II-2, Regulation 5 of SOLAS 74, as amended are excluded.

1.3 The test method covers the minimum requirements for fire extinguishing and prevention against re-ignition.

[1.4 This test method is applicable to gases, liquefied gases and mixtures of gases. For fire extinguishant gases mixed with compounds such as powders or liquids, this test method is only valid to the extent that these other compounds do not contribute to the extinguishment of the fire.]

[1.5 The test program has two objectives: (1) establishing the extinguishing effectiveness of a given agent at its tested concentration, and (2) establishing that the particular agent distribution system puts the agent into the enclosure in such a way as to fully flood the volume to achieve an extinguishing concentration at all points.]

### 2 Sampling

The components to be tested should be supplied by the manufacturer together with design and installation criteria, operational instructions, drawings, and technical data sufficient for the identification of the components.

### 3 Method of test

3.1 Principle

This test procedure enables the determination of the effectiveness of different gaseous agent extinguishing systems against spray fires, pool fires, and certain class A fires.

3.2 Apparatus

3.2.1 Test room

The tests should be performed in a room having a volume of at least 500 m3 with no horizontal dimension less than 6.5 m, and a minimum ceiling height of 5 m. The ratio of the room length to width should not exceed 2.0. The ceiling may be sloped or of sections of different height. The ratio of maximum to minimum ceiling height should not exceed 1.2.

3.2.2 Integrity of test enclosure

The test enclosure is to be nominally leak tight when doors and hatches are closed. The integrity of seals on doors, hatches, and other penetrations (e.g. instrumentation access ports) must be verified and recorded before each test. [Test enclosures should have an equivalent leakage area of __ $\pm$ 01m$^2$ as measured using a pressure differential fan test.]

3.2.3 Engine mock-up

.1 An engine mock-up of size (length x width x height) 1m x 3m x 3m should be constructed of sheet steel with a nominal thickness of 5mm. The mock-up should be fitted with two steel tubes diameter 0.3m and 3 m length (that simulate exhaust manifolds) and a solid steel plate. At the top of the mock-up a 3m2 tray should be arranged. See Figures 1,2 and 3. [Safeguards shall be provided to ensure that fuel cannot enter the void space inside the mock-up.]

.2 A floor plate system 4 m x 6 m x 0.75 m high surrounding the mock-up [with three trays, 2, 2, and 4 m2, equaling a total area of 8 m2, underneath,] should be as in Figures 1,2, and 3.

3.2.4 Instrumentation

Instrumentation for the continuos measurement and recording of test conditions should be employed. The following measurements should be made:

.1 temperature at three vertical positions (e.g., 1, 2.5, and 4.5 m)
.2 enclosure pressure
.3 gas sampling and analysis, at mid-room height, for oxygen, carbon dioxide, carbon monoxide, and relevant halogen acid products.
.4 means of determining flame-out indicators
.5 fuel nozzle pressure in the case of spray fires
.6 fuel flow rate in the case of spray fires

3.2.5 Nozzles

3.2.5.1 Nozzles should be located within 1 m of the ceiling

3.2.5.2 If more than one nozzle is used they should be symmetrically located.

3.3 Test fires & programme

3.3.1 Fire Types

The test programme, as described in Table 2, should employ test fires as described in Table 1.

| Table 1<br>Revised Parameters of Test Fires | | | | |
|---|---|---|---|---|
| Fire | Type | Fuel | Fire Size, MW | Remarks |
| A | 76 -n 100 mm ID Can | Heptane | 0.0012 to 0.002 | |
| B | .025 $m^2$ Tray | Heptane | .035 | |
| C | 1.25 $m^2$ Tray | Heptane | ~2.5 | |
| D | 1.25 $m^2$ Tray | Diesel/Fuel Oil | ~2 | |
| F | Low flow spray, heptane | Heptane 0.40 kg/min | 0.25 | Also use for re-ignition test |
| G | High flow spray, diesel/fuel oil | Diesel/Fuel Oil | 1.8 | Simulate fuel line rupture |
| H | Wood Crib | Spruce or Fir | 0.3 | Placed 0.3 - 0.6 m above fire B |
| I | [Electric cable fire] | To be determined | | [40 mm diameter PVC insulated cables and pipes] |

Notes to Table 1:

1. Diesel/Fuel Oil means light diesel or commercial fuel oil.

2. The wood crib should be substantially the same as described in ISO/TC 21/SC5/WG 8 ISO Draft International Standard, Gaseous fire extinguishing systems, Part 1: General Requirements. The crib should consist of six, trade size 50 mm x 50 mm by 450 mm long, kiln dried spruce or fir lumber having a moisture content between 9 and 13 percent. The members should be placed in 4 alternate layers at right angles to one another. Members should be evenly spaced forming a square structure.

Achieve ignition of the crib by burning commercial grade heptane in a square steel tray 0.25 m2 in area. During the pre-burn period the crib should be placed centrally above the top of the tray a distance of 300 to 600 mm.

Oil spray fire test parameters

| Fire type | Low pressure, Low flow | High pressure |
|---|---|---|
| Spray nossle | Wide spray angle (80°) full cone type | Standard angle (at 6 Bar) full cone type |
| Nominal oil pressure | 8.5 Bar | 150 Bar |
| Oil flow | 0.03 ± 0.005 kg/s | 0.050 ± 0.002 kg/s |
| Oil temperature | 20 ± 5° C | 20 ± 5° C |
| Nominal heat release rate | 1.1 ± 0.1 MW | 1.8 ± 0.2 MW |

Fire Locations

| Fire (from Table 1) | Fire Location |
|---|---|
| A | Heptane cans located in corners [and center] of the test enclosure. |
| B | 0.25m² tray [on deck plate centered below solid steel obstruction plate. One edge of the tray should be 100mm from the side of the engine mock-up.] |
| C | 1.25m² tray centered under the engine mock-up |
| D | Same location as Test C |
| F | Nozzle located under the solid steel plate in the location shown in Figure 2. |
| G | Nozzle located on top of the mock-up with spray impinging on the 50mm steel plate [impinging on the simulated exhaust manifold pipe] |
| H | 0.3 to 0.6 m above fire B |
| I | [A bundle of PVC cables/pipes placed up one wall and across one half of the width of the ceiling.] |

3.3.2 Test programme

The fire test programme should employ test fires singly or in combination, as outlined in Table 2.

Table 2 - Revised
Test Programme

| Test No. | | Fire Combinations | | Fire Load MW |
|---|---|---|---|---|
| 1 | A | Telltales, 8 room corners, 50 mm from walls, 150 mm below ceiling.<br>Test for agent distribution effectiveness | | |
| 2 | F<br>B<br>G | Low flow heptane spray directed at re-ignition rod<br>0.25 $m^2$ heptane tray under engine mockup<br>High flow diesel spray on top of simulated engine | 0.25 MW<br>0.35<br>1.8 | 2.4 |
| 3 | F<br>B<br>H<br>C | Low flow heptane spray directed at re-ignition rod<br>0.25 $m^2$ heptane tray under engine mockup<br>Wood crib placed above 0.25 $m^2$ heptane tray<br>1.25 $m^2$ heptane tray | 0.25 MW<br>0.35<br>0.3<br>2.5 | 3.4 |
| 4 | F<br>C<br>D | Low flow heptane spray directed at re-ignition rod<br>1.25 $m^2$ heptane tray<br>1.25 $m^2$ diesel tray | 0.25 MW<br>2.5<br>2 | 4.75 |
| 5 | [1] | [Electric cable fire test] | [To be developed] | |

Note to Table 2: Telltale fire cans should be located as follows:

(a) in upper corners of enclosure 150 mm below ceiling and 50 mm from each wall
(b) in corners on floors 50 mm from walls
[(c) Test 1 should be conducted with an agent concentration not exceeding 83% of the design concentration for which the manufacturer seeks approval to market nozzles and systems.]

3.3.2.1 [ Except for Test 1, all of the tests of Table 2 should be conducted for every new fire extinguishant gas, or mixture of gases, at the fire extinguishant system manufacturer's minimum proposed design concentration. ]

[3.3.2.2 Only Test 1 is required to evaluate new nozzles and related distribution system equipment (hardware) for systems employing fire extinguishants that have successfully completed Tests 1 through 5 at the proposed design concentration (or at a concentration lower than the proposed design concentration).]

[3.3.3 Re-ignition during 15 minute hold time: Re-ignition source to be developed.]

3.4 Extinguishing system

3.4.1 System installation

The extinguishing system should be installed according to the manufacturer's design and installation instructions. The maximum vertical distance should be limited to 5 m. The installation should comply with national or international standards as described in the guidelines.

3.4.2 Agent

3.4.2.1 Design concentration

The agent design concentration is that concentration (in volume per cent) required by system designer for the fire protection application.

3.4.2.2 Test concentration

The concentration of agent to be used in the fire extinguishing tests should be the design concentration specified by the extinguishing system manufacturer, except for Test 1 which should be conducted at 83% of the manufacturer's recommended design concentration.

3.4.2.3 Quantity of agent

The quantity of agent to be used should be determined as follows:

3.4.2.3.1 Halogenated agents

W = (V/S) ( C/(100-C) where

W = agent mass, kg
V = volume of test enclosure, m3
S = agent vapor specific volume at temperature and pressure of the test enclosure, kg/m3
C = gaseous agent concentration, volume per cent

3.4.2.3.2 Inert gas agents

Q = V[294/(273+T)] ( (P/1.013) ( ln[100/(100 - C)] where

Q = volume of inert gas, measured at 294 K and 1.013 bar, discharged, m3
V = volume of test enclosure, m3
T = test enclosure temperature, Celsius
P = test enclosure pressure, bar
C = gaseous agent concentration, volume per cent
(Reference NFPA 2001: 1994)

3.5 Procedure

3.5.1 Fuel levels in trays

The tray/s used in the test should be filled with at least 30 mm fuel on a water base. Freeboard should be 150 ± 10 mm.

3.5.2 Fuel flow and pressure measurements

For spray fires the fuel flow and pressure in the oil system should be measured before and during each test.

3.5.3 Ventilation

3.5.3.1 Pre-burn period

During the pre-burn period the test enclosure should be well ventilated. Oxygen levels as measured at the specified location(s) shall not fall below 20% prior to agent discharge.

3.5.2.3 End of pre-burn period

Doors, ceiling hatches, and other ventilation openings should be simultaneously closed at the end of the pre-burn period.

3.5.4 Duration of test

3.5.4.1 Pre-burn time

Fires should be ignited such that the following burning times occur before the start of agent discharge:

| | | |
|---|---|---|
| .1 | sprays - | 5 to 15 seconds |
| .2 | trays - | 2 minutes |
| .3 | crib - | 6 minutes |
| [.4 | cable - | 6 minutes] |

3.5.4.2 Discharge time

.1 halogenated agents should be discharged at a rate sufficient to achieve delivery of 95% of the minimum design quantity in 10 seconds or less.

.2 inert gas agents should be discharged at a rate sufficient to achieve 85% of the minimum design quantity in 120 seconds or less.

3.5.4.3 Soak time

After the end of agent discharge the test enclosure should be kept closed for 15 minutes.

3.5.5 Measurements and observations

3.5.5.1 Before test

.1 temperature of test enclosure, fuel and engine mock-up
.2 initial weights of agent containers
.3 verification of integrity agent distribution system and nozzles
.4 initial weight of wood crib

3.5.5.2 During test

.1 start of the ignition procedure
.2 start of the test (ignition)
.3 time when ventilating openings are closed
.4 time when the extinguishing system is activated
.5 time from end of agent discharge
.6 time when the oil flow for the spray fire is shut off
.7 time when all fires are extinguished
.8 time of re-ignition, if any, during soak period
.9 time at end of soak period at which point doors should be opened, enclosure vented
.10 at the start of test initiate continuous monitoring as per 3.2.4.3

3.5.6 Tolerances

Unless otherwise stated, the following tolerances should apply:

| | | |
|---|---|---|
| .1 | Length | ±2% of value |
| .2 | Volume | ±5% of value |
| .3 | Pressure | ±3% of value |
| .4 | Temperature | ±5% of value |
| [.5 | Concentration | ±5% of value] |

These tolerances are in accordance with ISO standard 6182/1, February 1994 edition [4]. [(excludes concentration)]

4. Classification criteria

4.1 Class B fires must be extinguished within 30 seconds of the end of agent discharge. At the end of the soak period there should be no re-ignition upon opening the enclosure.

4.2 The oil spray should be shut off 15 seconds after extinguishment. At the end of the soak time the oil spray should be restarted for 15 seconds prior to reopening the door, and there should be no reignition.

4.3 At the end of the test fuel trays must contain sufficient fuel to cover the bottom of the tray.

4.4 Wood crib weight loss must be no more than 60%.

4.5 For use on passeneger vessels, hazards created by decomposition of the fire extinguishing agent shall not exceed similar hazards created by halon 1301.

5. Test report

The test report should include the following information:

.1 Name and address of the test laboratory
.2 Date and identification number of the test report
.3 Name and address of client
.4 Purpose of the test
.5 Method of sampling system components
.6 Name and address of manufacturer or supplier of the product
.7 Name or other identification marks of the product
.8 Description of the tested product
- drawings
- descriptions
- assembly instructions
- specification of included materials
- detailed drawing of test set-up
.9 Date of supply of the product
.10 Date of test
.11 Test method
.12 Drawing of each test configuration
.13 Identification of the test equipment and used instruments
.14 Conclusions
.15 Deviations from the test method, if any
.16 Test results including observations during and after the test; and
.17 Date and signature

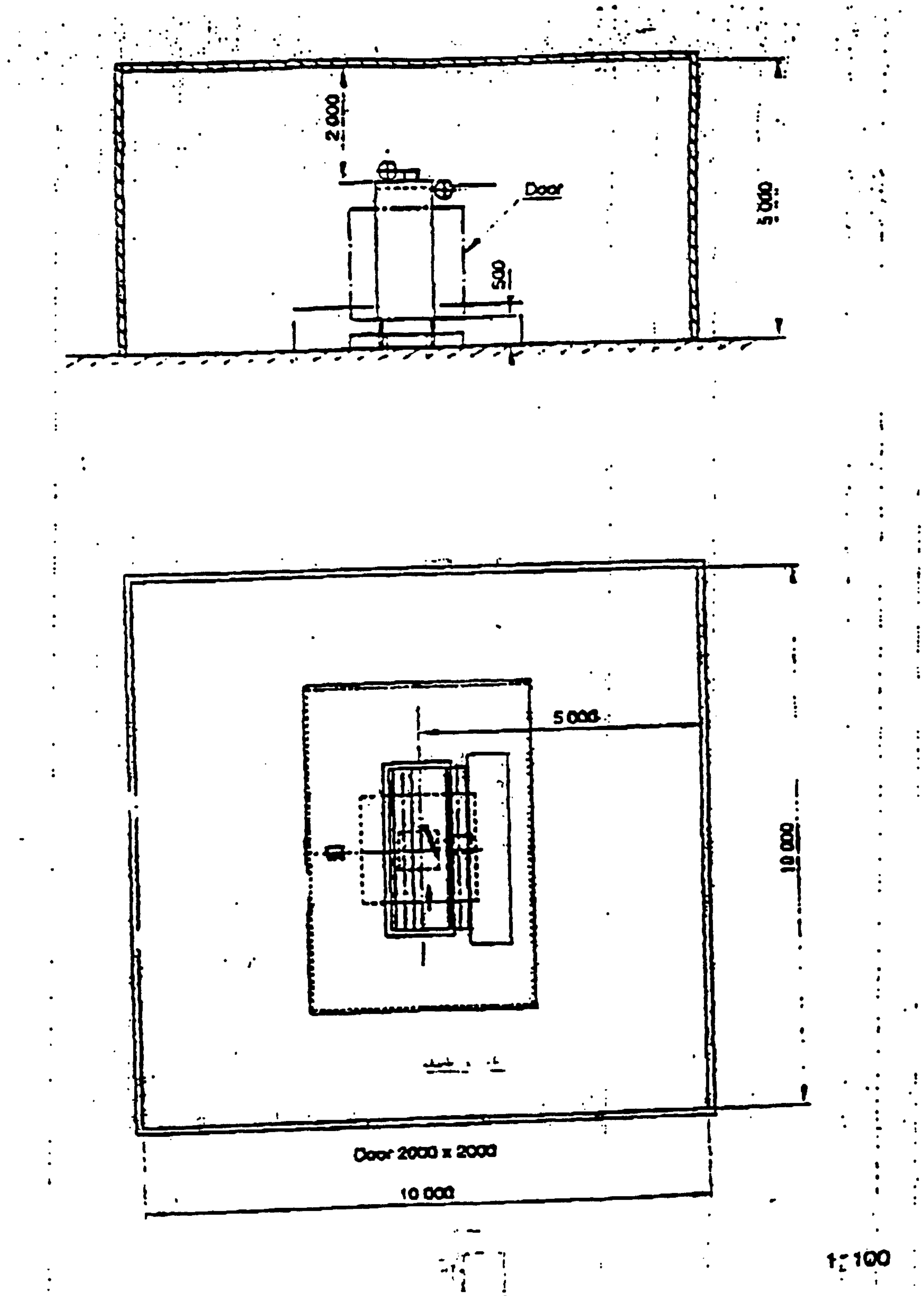


Figure 1

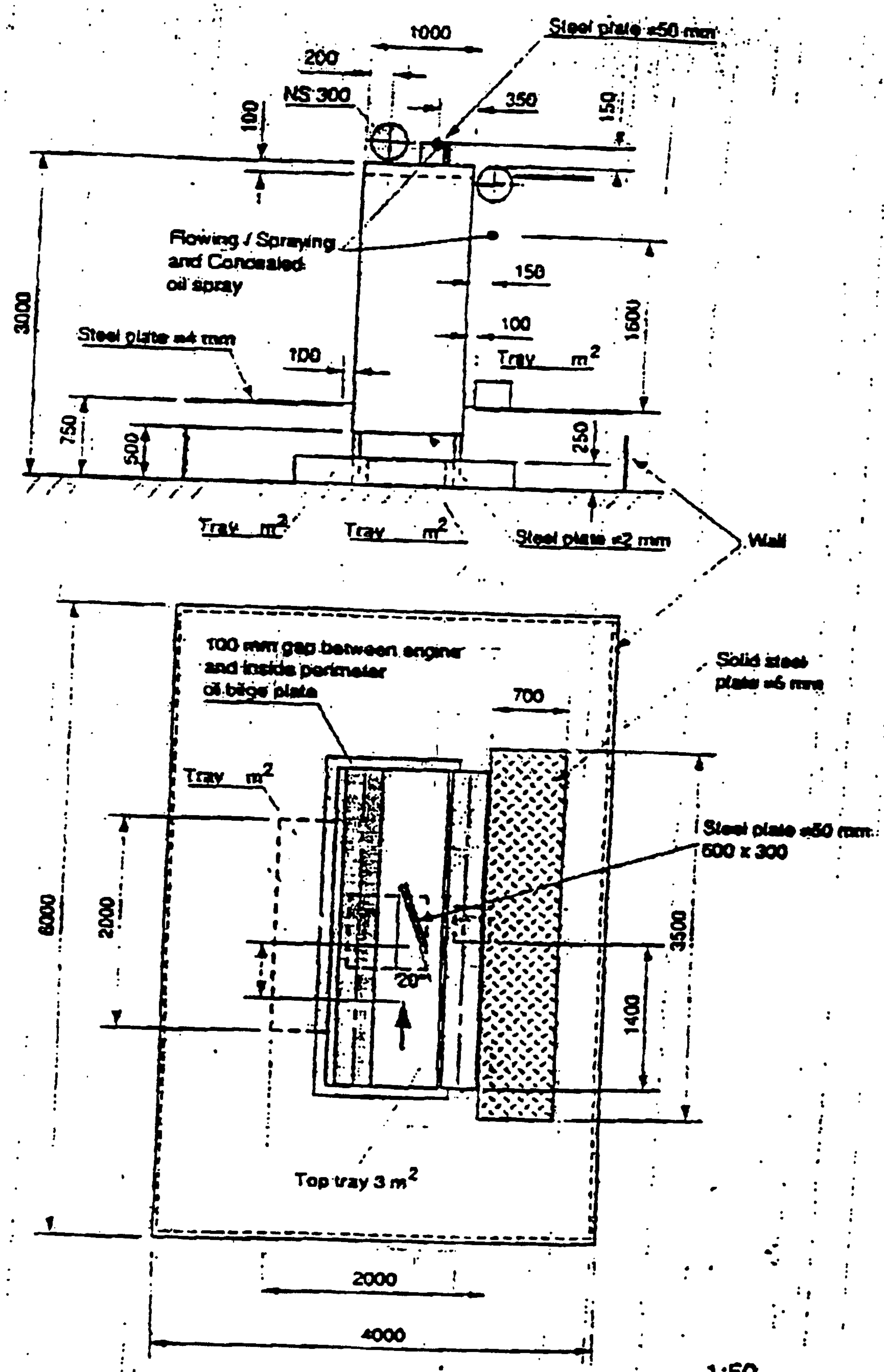
1000
200
Steel plate ≈50 mm
NS 300
350
150
100
Flowing / Spraying and Concealed oil spray
150
3000
100
1500
Steel plate ≈4 mm
100
Tray m²
750
500
250
Tray m²
Tray m²
Steel plate ≈2 mm
Wall
100 mm gap between engine and inside perimeter oil bilge plate
Solid steel plate ≈6 mm
700
Tray m²
Steel plate ≈50 mm 600 x 300
6000
2000
3500
20°
1400
Top tray 3 m²
2000
4000
1:50

Figure 2

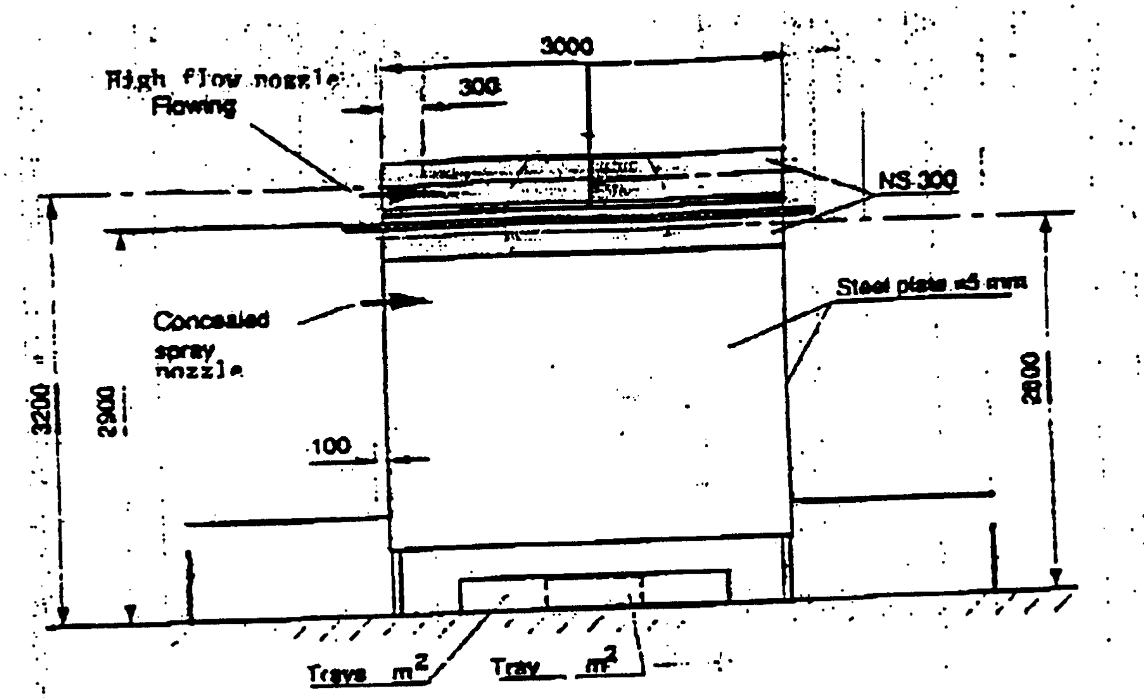
3000
High flow nozzle
Flowing
300
NS 300
Steel plate ≈5 mm
Concealed
spray
nozzle
3200
2900
2800
100
Trays m2
Tray m2

FIG 3

***

## ANNEX 2

Proposed Revisions to:
Draft Guidelines for Equivalent Fixed Gas Fire-Extinguishing Systems as Referred to In SOLAS 74 for Machinery Spaces and Cargo Pump Rooms

Revise Paragraph 6: No fire suppression system should be used which is carcinogenic, mutagenic, or teratogenic at concentrations expected to be used on ships. No agent should be used in concentrations greater than the cardiac sensitization NOAEL (No Observable Adverse Effect Level) or ALC (Approximate Lethal Concentration), without the use of controls as set down in SOLAS 74 regulation II-2/5.2.5.1 and 5.2.5.2. In no case should an agent be used above its LOAEL (Lowest Observable Adverse Effect Level) [unless the following conditions apply:]

- Operational requirements necessitate concentrations above the LOAEL.
- The LOAEL is based on cardiac sensitization as determined by an appropriate authority.
- Other than as influenced by the fire extinguishing agent itself, occupants are likely to be capable of self preservation at the time of system actuation.
- Ready means of egress is provided from the protected space.
- Means of egress shall be available for immediate use at all times.
- The maximum egress time shall not exceed 20 seconds.
- Controls and warnings: To be developed.

Paragraph 6 Note: A universal warning, indicating the imminent release of life threatening fire suppression agents needs to be developed. The warning should be audible and visual. In addition, for spaces that are unmanned at times, an odor should be added to life threatening fire extinguishing gases to warn entering personnel of the presence of gas in a space.

New paragraph 12:
For all ships, the fire extinguishing system design manual should address recommended procedures for the control of products of agent decomposition. The performance of fire extinguishing arrangements on passenger ships should not present health hazards from decomposed extinguishing agents that exceed those created by the use of halon 1301.

## ANNEX 1

## PROPOSED AMENDMENT TO CHAPTER II-2 OF THE INTERNATIONAL CONVENTION FOR THE SAFETY OF LIFE AT SEA, 1974

*Replace regulation 21 by the following.*

**"Regulation 21**

***Fire-fighting training, operations, and maintenance***

1 Operational readiness, maintenance and inspections

1.1 All fire-fighting systems and appliances shall be kept in good operating order and available for immediate use at all times during the voyage and in port.

1.2 On-board maintenance and inspections of active and passive fire protection systems and appliance shall be carried out in accordance with the guidelines developed by the Organization.*

1.3 The Administrations may accept, in lieu of the instructions required by paragraph 1.2, a shipboard planned maintenance programme which includes procedures and schedules for the testing, inspection, and maintenance for all fire-fighting systems and appliances if covered by the Safety Management System as required by the International Safety Management (ISM) Code adopted by the Organization. Such maintenance programmes may be computer based.

2 Basic safety training

2.1 Crew members assigned fire-fighting duties shall receive basic safety training in the use of the ship's fire-fighting appliances at the same interval as the drills. Individual instructions may cover different parts of the ship, but all the ships fire-fighting systems and appliances shall be covered in a period of one year. Such training shall be based on Chapter VI, Section A-VI/2.1.2, Table A-VI/1-2 of the STCW Code.

2.2 Training and drills shall be recorded in accordance with regulation III/18.6. However, such records may be computer based.

---

* Refer to the guidelines to be developed by the Organization

4 The Correspondence Group also agreed to inco:
Regulations III/18 and III/19, and Chapter VI of the ST
were similar to the work of the Correspondence Group
between the proposed amendments to Chapter II-2 and
opinion that references to training requirements should
provides comprehensive guidance on such issues. It is
Comprehensive Review, the FP Sub-Committee consid
protection requirements contained in Chapters III with
requirements into Chapter II-2.

5 The ongoing work of the Correspondence Grou
also considered with a view toward future incorporatio
the new structure of Chapter II-2. Thus, the draft amer
divided by operations, maintenance, and training to coi
Safety Requirements".

**Action requested of the Sub-Committee**

6 The Sub-Committee is invited to:

.1 approve the draft amendments to Regul
and

.2 approve the draft resolution on Proposec
Readiness, Maintenance and Inspection
Appliances as contained in Annex 2.

***

# ANNEX 2

## DRAFT GUIDELINES ON OPERATIONAL READINESS, MAINTENANCE AND INSPECTION OF FIRE PROTECTION SYSTEMS AND APPLIANCES

**1 This guideline applies to all ships.**

**2 Operational readiness**

All fire protection systems and appliances should at all times be in good order and available for immediate use during the voyage and in port. If a fire protection system is under repair then suitable arrangements shall be made to ensure safety is not diminished.

**3 Maintenance and testing**

Instructions for onboard maintenance, not necessarily by the ship's crew, and testing of active and passive fire protection systems and appliances shall be easily understood, illustrated wherever possible, and, as appropriate, shall include the following for each system or appliance:

.1 maintenance and repair instructions;

.2 schedule of periodic maintenance

.3 list of replaceable parts;

.4 log for records of inspections and maintenance listing identified non-conformities and their targeted completion dates.

**4 Monthly testing and inspections**

Monthly inspections should be carried out to ensure that:

.1 all fireman's outfits, fire extinguishers, fire hydrants, hose and nozzles are in place, properly arranged, and are in proper condition;

.2 all escape routes including stairways and corridors are properly maintained and free of obstructions;

.3 public address system and ship's alarms are tested;

.4 all fixed fire-fighting system stop valves are in the proper open or closed position for operational readiness;

3 Operations*

3.1 Training materials [or a booklet] on general fire safety and operation of the ship's fire-fighting appliances shall be placed in each crew messroom and recreation room or in each crew cabin.

3.2 Training materials [or a booklet] shall contain instructions and information, in easily understood terms illustrated wherever possible, on general fire safety and the operation of the ship's fire-fighting appliances. As a minimum, the training booklet shall cover the Familiarization training contained in Chapter VI, Section A-VI/1.1 of the STCW Code.

---

* Refer to the Safety Management System of the ISM Code

***

.4 all fire pumps, including sprinkler system pumps, are flow tested for proper pressures and flows;

.5 all hydrants are tested for operation;

.6 all antifreeze systems are tested for proper solutions;

.7 sprinkler system connections from the ship's fire main are tested for operation; and

.8 [fire detection systems.]

7 **Five-year service**

At least once every five years, the following should be inspections and tests should be carried out:

.1 control valves of fixed fire-fighting systems should be internally inspected: and

.2 air should be blown through the piping of extinguishing gas systems.

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# Appendix B

## Instrumentation and Camera Details

F.I.R.E.S.

Test Name: IMO Protocol Evaluation

Instrument List & Test Requirements

Sheet: 1

Time for Each Test: < 25 min

Test Series: 98GA

Scan Interval: 6 sec.

Total Number of Tests:

Project Number: 3302/3308.1.98

| Channel # | SP | RE | ID | Instrumentation Description | Serial Number | Output Range Eng. Unit | Location | Remarks/Notes |
|---|---|---|---|---|---|---|---|---|
| 0 | | | X | Humidity | 8292031 | 0-100% R.H. | Near Trailer | Ambient |
| 1 | | | X | Barometer | | 91-106 kPa | Near Trailer | Ambient |
| 2 | | | X | Wind - Intensity | | 0-44 m/s | High Spot on Ship | Ambient |
| 3 | | | X | Wind - Direction | | 0-360° | High Spot on Ship | Ambient 0° = Bow |
| 4 | | | X | TC reference junction | | 0-50°C | Near Trailer | |
| 5 | | 25 | X | TC | | 0-800°C | (3.0, 5.0, 4.9) | TC Tree 1 |
| 6 | | 25 | | TC | | 0-800°C | (3.0, 5.0, 4.5) | TC Tree 1 |
| 7 | | 25 | | TC | | 0-800°C | (3.0, 5.0, 4.0) | TC Tree 1 |
| 8 | | 25 | | TC | | 0-800°C | (3.0, 5.0, 3.5) | TC Tree 1 |
| 9 | | 25 | | TC | | 0-800°C | (3.0, 5.0, 3.0) | TC Tree 1 |
| 10 | | 25 | | TC | | 0-800°C | (3.0, 5.0, 2.5) | TC Tree 1 |
| 11 | | 25 | | TC | | 0-800°C | (3.0, 5.0, 1.5) | TC Tree 1 |
| 12 | | 25 | | TC | | 0-800°C | (3.0, 5.0, 1.0) | TC Tree 1 |
| 13 | | 25 | | TC | | 0-800°C | (7.0, 5.0, 4.9) | TC Tree 2 |
| 14 | | 25 | | TC | | 0-800°C | (7.0, 5.0, 4.5) | TC Tree 2 |
| 15 | | 25 | | TC | | 0-800°C | (7.0, 5.0, 4.0) | TC Tree 2 |
| 16 | | 25 | | TC | | 0-800°C | (7.0, 5.0, 3.5) | TC Tree 2 |
| 17 | | 25 | | TC | | 0-800°C | (7.0, 5.0, 3.0) | TC Tree 2 |
| 18 | | 72 | | TC | | 0-800°C | (7.0, 5.0, 2.5) | TC Tree 2 |
| 19 | | 72 | | TC | | 0-800°C | (7.0, 5.0, 1.5) | TC Tree 2 |
| 20 | | 72 | | TC | | 0-800°C | (7.0, 5.0, 1.0) | TC Tree 2 |
| 21 | X | 72 | | TC | | 0-800°C | (0.0, 0.0, 4.9) | Tell tale #1 |
| 22 | X | 72 | | TC | | 0-800°C | (0.0, 0.0, 0.2) | Tell tale #2 |
| 23 | X | 72 | | TC | | 0-800°C | (9.9, 0.0, 4.9) | Tell tale #3 |
| 24 | X | 72 | | TC | | 0-800°C | (9.9, 0.0, 0.2) | Tell tale #4 |
| 25 | | | | TC reference junction | | 0-50°C | Rear Cable Box | Chnl 5-17 |

| Test Series: | | | | 98GA | Test Requirements | | Time for Each Test: | < 25 min |
|---|---|---|---|---|---|---|---|---|
| Total Number of Tests: | | | | | | | Scan Interval: | 6 sec. |
| Project Number: 3302/3308.1.98 | | | | | | | | |
| | Channel | | | | | Output Range | | |
| # | SP | RE | ID | Instrumentation Description | Serial Number | Eng. Unit | Location | Remarks/Notes |
| 26 | X | 72 | | TC Type K | | 0-800°C | (9.9, 9.9, 4.9) | Tell tale #5 |
| 27 | X | 72 | | TC Type K | | 0-800°C | (9.9, 9.9, 0.2) | Tell tale #6 |
| 28 | X | 72 | | TC Type K | | 0-800°C | (0.0, 9.9, 4.9) | Tell tale #7 |
| 29 | X | 72 | | TC Type K | | 0-800°C | (0.0, 9.9, 0.2) | Tell tale #8 |
| 30 | X | 72 | | TC Type K | | 0-800°C | (5.0, 5.0, 0.4) | Abv Fire B&D pans |
| 31 | | 72 | | TC Type K | | 0-800°C | (5.0, 5.0, 0.3) | Fire B & D Ent. |
| 32 | X | 73 | | TC Type K | | 0-800°C | (5.0, 4.0, 1.0) | Abv Fire C 2m$^2$pan |
| 33 | | 73 | | TC Type K | | 0-800°C | (5.0, 4.0, 0.8) | Fire C Ent. |
| 34 | X | 73 | | TC Type K | | 0-800°C | (5.0, 5.0, 3.3) | Abv Fire E LP spray |
| 35 | | 73 | | TC Type K | | 0-800°C | (5.0, 4.4, 3.2) | Fire E Ent. |
| 36 | X | 73 | | TC Type K | | 0-800°C | (5.7, 5.6, 2.4) | Abv Fire F LP/LF spr |
| 37 | | 73 | | TC Type K | | 0-800°C | (6.5, 5.6, 2.4) | Fire F Ent. |
| 38 | X | 73 | | TC Type K | | 0-800°C | (5.0, 5.0, 3.5) | Abv Fire G HP spray |
| 39 | | 73 | | TC Type K | | 0-800°C | (5.0, 5.0, 3.0) | Fire G Ent. |
| 40 | X | 73 | | TC Type K | | 0-800°C | (5.0, 2.3,0.9) | Abv Wood Crib Fire |
| 41 | | 73 | | TC Type K | | 0-800°C | (5.0,2.3, 0.7) | Wood Crib Fire Ent. |
| 42 | | | X | CO Analyzer | | 0-5% | (3.0, 5.0, 4.0) | Gas Tree #1 |
| 43 | | | X | $CO_2$ Analyzer | | 0-15% | (3.0, 5.0, 4.0) | Gas Tree #1 |
| 44 | X | | X | $O_2$ Analyzer | | 0-25% | (3.0, 5.0, 4.0) | Gas Tree #1 |
| 45 | | | | CO Analyzer | | 0-5% | (3.0, 5.0, 2.5) | Gas Tree #1 |
| 46 | | | | $CO_2$ Analyzer | | 0-15% | (3.0, 5.0, 2.5) | Gas Tree #1 |
| 47 | X | | | $O_2$ Analyzer | | 0-25% | (3.0, 5.0, 2.5) | Gas Tree #1 |
| 48 | | | | CO Analyzer | | 0-5% | (3.0, 5.0, 1.0) | Gas Tree #1 |
| 49 | | | | $CO_2$ Analyzer | | 0-15% | (3.0, 5.0, 1.0) | Gas Tree #1 |
| 50 | X | | | $O_2$ Analyzer | | 0-21% | (3.0, 5.0, 1.0) | Gas Tree #1 |

F.I.R.E.S.

Test Name: IMO Protocol Evaluation

Instrument List & Test Requirements

Sheet: 3

Test Series: 98GA

Time for Each Test: < 25 min

Total Number of Tests:

Scan Interval: 6 sec.

Project Number: 3302/3308.1.98

| Channel # | SP | RE | ID | Instrumentation Description | Serial Number | Output Range Eng. Unit | Location | Remarks/Notes |
|---|---|---|---|---|---|---|---|---|
| 51 | | | | CO Analyzer | | 0-5% | (7.0, 5.0, 4.0) | Gas Tree #2 |
| 52 | | | | $CO_2$ Analyzer | | 0-15% | (7.0, 5.0, 4.0) | Gas Tree #2 |
| 53 | | | | $O_2$ Analyzer | | 0-25% | (7.0, 5.0, 4.0) | Gas Tree #2 |
| 54 | | | | CO Analyzer | | 0-5% | (7.0, 5.0, 2.5) | Gas Tree #2 |
| 55 | | | | $CO_2$ Analyzer | | 0-15% | (7.0, 5.0, 2.5) | Gas Tree #2 |
| 56 | | | | $O_2$ Analyzer | | 0-25% | (7.0, 5.0, 2.5) | Gas Tree #2 |
| 57 | | | X | CO Analyzer | | 0-5% | (7.0, 5.0, 1.0) | Gas Tree #2 |
| 58 | | | | $CO_2$ Analyzer | | 0-15% | (7.0, 5.0, 1.0) | Gas Tree #2 |
| 59 | | | | $O_2$ Analyzer | | 0-25% | (7.0, 5.0, 1.0) | Gas Tree #2 |
| 60 | | | X | Radiometer | | 0-50 $kW/m^2$ | (5.0, 10.0, 4.0) | STBD blkhd |
| 61 | | | X | Calorimeter | | 0-50 $kW/m^2$ | (5.0, 10.0, 4.0) | STBD blkhd |
| 62 | | | | Radiometer | | 0-50 $kW/m^2$ | (5.0, 10.0, 1.8) | STBD blkhd |
| 63 | | | | Calorimeter | | 0-50 $kW/m^2$ | (5.0, 10.0, 1.8) | STBD blkhd |
| 64 | | | | Radiometer | | 0-50 $kW/m^2$ | (0.0, 5.0, 4.0) | AFT blkhd |
| 65 | | | | Calorimeter | | 0-50 $kW/m^2$ | (0.0, 5.0, 4.0) | AFT blkhd |
| 66 | | | | Radiometer | | 0-50 $kW/m^2$ | (0.0, 5.0, 1.8) | AFT blkhd |
| 67 | | | | Calorimeter | | 0-50 $kW/m^2$ | (0.0, 5.0, 1.8) | AFT blkhd |
| 68 | | | X | Pressure Transducer | | +/- 1244 Pa | (5.0, 0.0, 2.5) | Exting Sys Data Acq |
| 69 | | | | Pressure Transducer | | +/- 1244 Pa | (5.0, 10.0, 2.5 | Exting Sys Data Acq |
| 70 | | | X | Pressure Transducer | | 0-1700 kPa | in fuel line | LP Fuel Sys. |
| 71 | | | X | Pressure Transducer | | 0-20000 kPa | in fuel line | HP Fuel Sys |
| 72 | | | | TC reference junction | | 0-50 °C | Near cable box | Chnl 18-31 |
| 73 | | | | TC reference junction | | 0-50 °C | Near cable box | Chnl 32-41 |
| 240 | | | | Time Date Generator | | | | |
| 241 | | | | Scanning Alarm | | | | |

**BRENDLE**
**INCORPORATED**

433 N. DECATUR STREET • P.O. BOX 1868 • MONTGOMERY, ALABAMA 36102 • Phone 262-0505 • FAX 264-2381

TELEPHONE: 334-262-0505
TELEFAX: BUSINESS OFFICE 334-264-2381

## FAX MESSAGE

DATE: 6-18-96
PLEASE DELIVER THE FOLLOWING FAX MESSAGE TO:
NAME: Rich Hansen
COMPANY: U.S. Coast Guard
FROM: Brendle Inc
TOTAL NUMBER OF PAGES (INCLUDING THIS COVER SHEET): 9
WE ARE SENDING FROM A CANON 270. IF THE FAX MESSAGE YOU RECEIVE IS INCOMPLETE OR ILLEGIBLE, OUR TELEPHONE NUMBER IS 334-262-0505.

## ENCLOSURE INTEGRITY TEST REPORT

### TEST IDENTIFICATION INFORMATION

| | |
|---|---|
| Disk Data File: | C.GUARD.HAL |
| Program: | INFILTEC LA version 06/20/94 |
| Registered Owner | Brendle, Inc. |
| Test Date: | JUNE 17, 1996 |
| Test Time: | 1:00 PM |
| Job ID: | COAST GUARD |
| Room ID: | ENGINE TEST ROOM |
| Tested By: | BRENDLE |
| Backflow Relief: | YES |
| HVAC on or off: | OFF |
| Damper Position: | CLOSED |
| Static Pressure: | 0.00 |
| Comments: | NONE |

### ENCLOSURE, ENVIRONMENT, AND SYSTEM DATA

| | | |
|---|---|---|
| Gas | = | 1301 Density= 6.283 kg/m3 @ STP |
| Protected Volume | (cu ft)= | 17816 |
| Maximum Protected Height | (ft)= | 17 |
| Minimum Protected Height | (ft)= | 8 |
| Temperature Inside Space | (F)= | 85 |
| Temperature Around Space | (F)= | 85 |
| Gas Design Concentration | (%)= | 5 |
| Optional: Upper leakage | (sq ft)= | ? |
| Computed Floor Area | (sq ft)= | 1048 |
| Computed Max Gas Pres | (in wc)= | .051863048 |

### PRETEST PREDICTION FOR 10 MIN HOLD

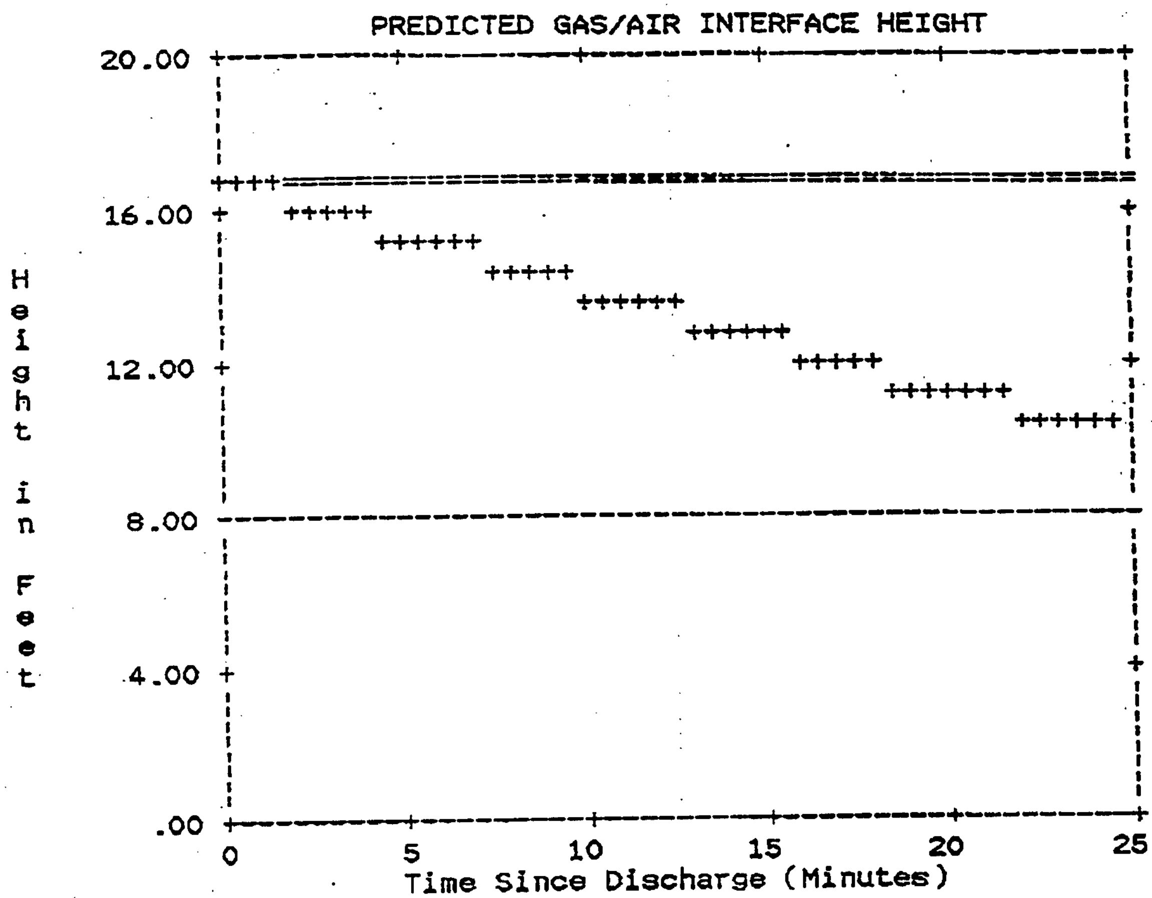
Pretest Prediction Estimated From NFPA 2001-1994 Calculation
Maximum Acceptable Hole (sq in)= 860.8891104 or (sq ft)= 5.9783966

### PRESSURE AND FLOW MEASUREMENTS

| | | |
|---|---|---|
| Static Pressure | (in wc)= | 0.00 |
| Room Depressurization | (in wc)= | .060 |
| Flow Gauge | (cfm)= | 2300 |
| Orifice Plate | (ratio)= | 2.05 |
| Room Pressurization | (in wc)= | .060 |
| Flow Gauge | (cfm)= | 2100 |
| Orifice Plate | (ratio)= | 2.05 |

### GAS RETENTION PREDICTIONS

NFPA 2001-94 Prediction of 1/2 Concentration Interface
Hole Area (sq in)= 257.8986144 or (sq ft)= 1.7909626
Hold Time (min)= 33.382153




Plots: = is Maximum Protected Height, - is Minimum Protected,
+ is NFPA Calculation

# ENCLOSURE INTEGRITY TEST REPORT

## TEST IDENTIFICATION INFORMATION

| | |
|---|---|
| Disk Data File: | C.GUARD.HAL |
| Program: | INFILTEC LA version 06/20/94 |
| Registered Owner | Brendle, Inc. |
| Test Date: | JUNE 17, 1996 |
| Test Time: | 1:00 PM |
| Job ID: | COAST GUARD |
| Room ID: | ENGINE TEST ROOM |
| Tested By: | BRENDLE |
| Backflow Relief: | YES |
| HVAC on or off: | OFF |
| Damper Position: | CLOSED |
| Static Pressure: | 0.00 |
| Comments: | NONE |

## ENCLOSURE, ENVIRONMENT, AND SYSTEM DATA

| | |
|---|---|
| Gas | = FM-200 Density= 7.26 kg/m3 @ STP |
| Protected Volume | (cu ft)=17816 |
| Maximum Protected Height | (ft)=17 |
| Minimum Protected Height | (ft)=8 |
| Temperature Inside Space | (F)=85 |
| Temperature Around Space | (F)=85 |
| Gas Design Concentration | (%)=8.7 |
| Optional: Upper leakage | (sq ft)=? |
| Computed Floor Area | (sq ft)= 1048 |
| Computed Max Gas Pres | (in wc)= .10759382 |

## PRETEST PREDICTION FOR 10 MIN HOLD

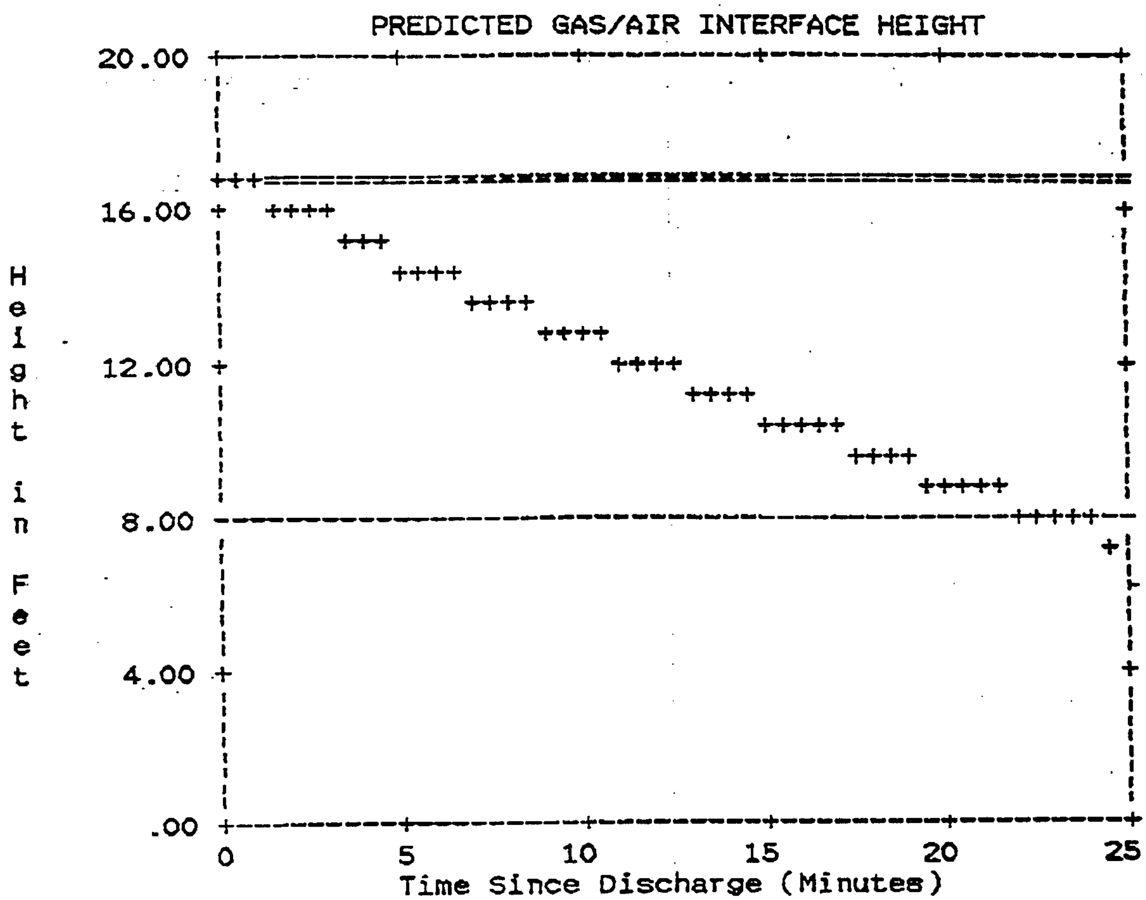
Pretest Prediction Estimated From NFPA 2001-1994 Calculation
Maximum Acceptable Hole (sq in)= 627.6424032 or (sq ft)= 4.3586278

## PRESSURE AND FLOW MEASUREMENTS

| | |
|---|---|
| Static Pressure | (in wc)=0.00 |
| Room Depressurization | (in wc)=.120 |
| Flow Gauge | (cfm)=3400 |
| Orifice Plate | (ratio)=2.05 |
| Room Pressurization | (in wc)=.120 |
| Flow Gauge | (cfm)=3200 |
| Orifice Plate | (ratio)=2.05 |

## GAS RETENTION PREDICTIONS

NFPA 2001-94 Prediction of 1/2 Concentration Interface
Hole Area (sq in)= 273.5427888 or (sq ft)= 1.8996027
Hold Time (min)= 22.945797




Plots: = is Maximum Protected Height, - is Minimum Protected,
+ is NFPA Calculation

# ENCLOSURE INTEGRITY TEST REPORT

## TEST IDENTIFICATION INFORMATION

| | |
|---|---|
| Disk Data File: | C.GUARD.HAL |
| Program: | INFILTEC LA version 06/20/94 |
| Registered Owner | Brendle, Inc. |
| Test Date: | JUNE 17, 1996 |
| Test Time: | 1:00 PM |
| Job ID: | COAST GUARD |
| Room ID: | ENGINE TEST ROOM |
| Tested By: | BRENDLE |
| Backflow Relief: | YES |
| HVAC on or off: | OFF |
| Damper Position: | CLOSED |
| Static Pressure: | 0.00 |
| Comments: | NONE |

## ENCLOSURE, ENVIRONMENT, AND SYSTEM DATA

Gas = CEA-410 Density= 9.85 kg/m3 @ STP
Protected Volume (cu ft)=17816
Maximum Protected Height (ft)=17
Minimum Protected Height (ft)=8
Temperature Inside Space (F)=85
Temperature Around Space (F)=85
Gas Design Concentration (%)=8
Optional: Upper leakage (sq ft)=?

Computed Floor Area (sq ft)= 1048
Computed Max Gas Pres (in wc)= .1412357

## PRETEST PREDICTION FOR 10 MIN HOLD

Pretest Prediction Estimated From NFPA 2001-1994 Calculation
Maximum Acceptable Hole (sq in)= 563.004216 or (sq ft)= 3.9097515

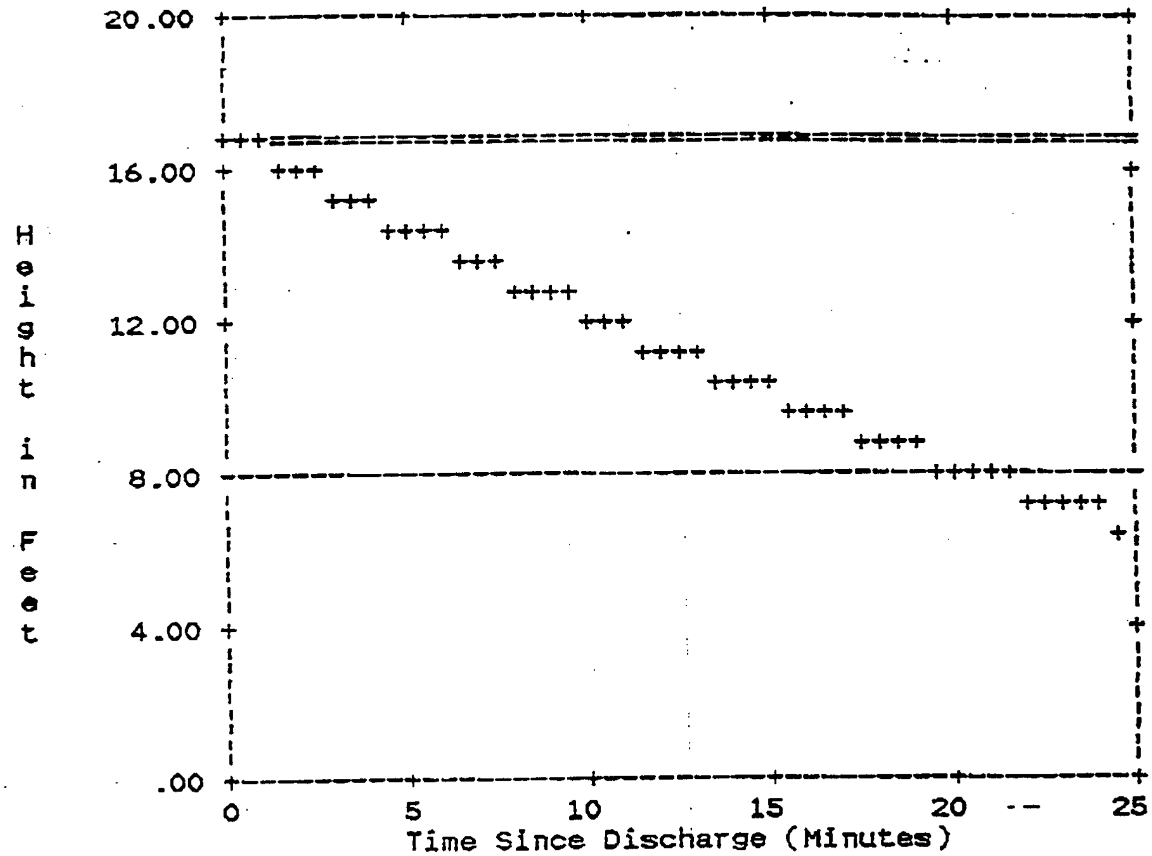
## PRESSURE AND FLOW MEASUREMENTS

Static Pressure (in wc)=0.00
Room Depressurization (in wc)=.160
Flow Gauge (cfm)=3900
Orifice Plate (ratio)=2.05
Room Pressurization (in wc)=.160
Flow Gauge (cfm)=3750
Orifice Plate (ratio)=2.05

## GAS RETENTION PREDICTIONS

NFPA 2001-94 Prediction of 1/2 Concentration Interface
Hole Area (sq in)= 274.5828576 or (sq ft)= 1.9068254
Hold Time (min)= 20.504745

PREDICTED GAS/AIR INTERFACE HEIGHT




Plots: = is Maximum Protected Height, - is Minimum Protected,
+ is NFPA Calculation

# ENCLOSURE INTEGRITY TEST REPORT

## TEST IDENTIFICATION INFORMATION

| | |
|---|---|
| Disk Data File: | C.GUARD.HAL |
| Program: | INFILTEC LA version 06/20/94 |
| Registered Owner | Brendle, Inc. |
| Test Date: | JUNE 17, 1996 |
| Test Time: | 1:00 PM |
| Job ID: | COAST GUARD |
| Room ID: | ENGINE TEST ROOM |
| Tested By: | BRENDLE |
| Backflow Relief: | YES |
| HVAC on or off: | OFF |
| Damper Position: | CLOSED |
| Static Pressure: | 0.00 |
| Comments: | NONE |

## ENCLOSURE, ENVIRONMENT, AND SYSTEM DATA

| | |
|---|---|
| Gas | = NAF-SIII Density= 3.84 kg/m3 @ STP |
| Protected Volume | (cu ft)=17816 |
| Maximum Protected Height | (ft)=17 |
| Minimum Protected Height | (ft)=8 |
| Temperature Inside Space | (F)=85 |
| Temperature Around Space | (F)=85 |
| Gas Design Concentration | (%)=12 |
| Optional: Upper leakage | (sq ft)=? |
| Computed Floor Area | (sq ft)= 1048 |
| Computed Max Gas Pres | (in wc)= .064624153 |

## PRETEST PREDICTION FOR 10 MIN HOLD

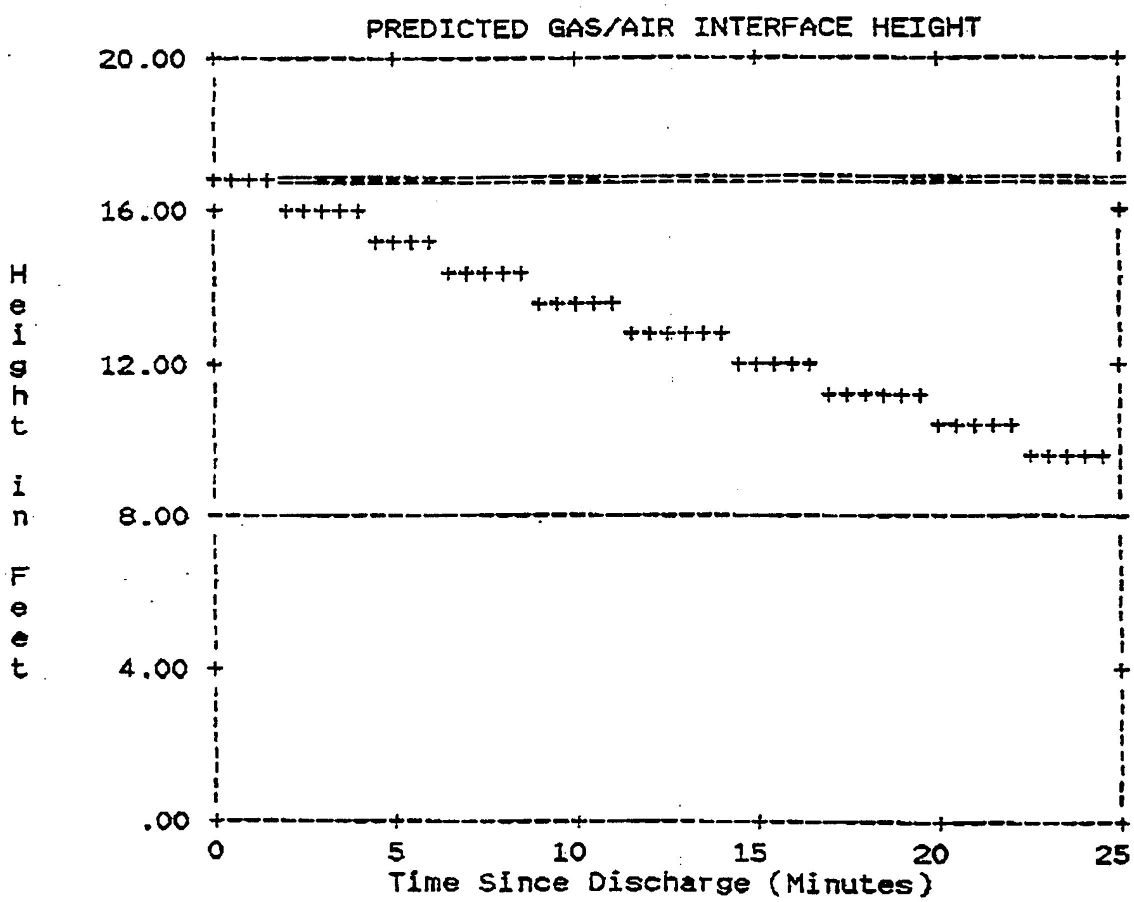
Pretest Prediction Estimated From NFPA 2001-1994 Calculation
Maximum Acceptable Hole (sq in)= 780.2366976 or (sq ft)= 5.4183104

## PRESSURE AND FLOW MEASUREMENTS

| | |
|---|---|
| Static Pressure | (in wc)=0.00 |
| Room Depressurization | (in wc)=.070 |
| Flow Gauge | (cfm)=2500 |
| Orifice Plate | (ratio)=2.05 |
| Room Pressurization | (in wc)=.070 |
| Flow Gauge | (cfm)=2250 |
| Orifice Plate | (ratio)=2.05 |

## GAS RETENTION PREDICTIONS

NFPA 2001-94 Prediction of 1/2 Concentration Interface
Hole Area (sq in)= 257.7606048 or (sq ft)= 1.7900042
Hold Time (min)= 30.270945



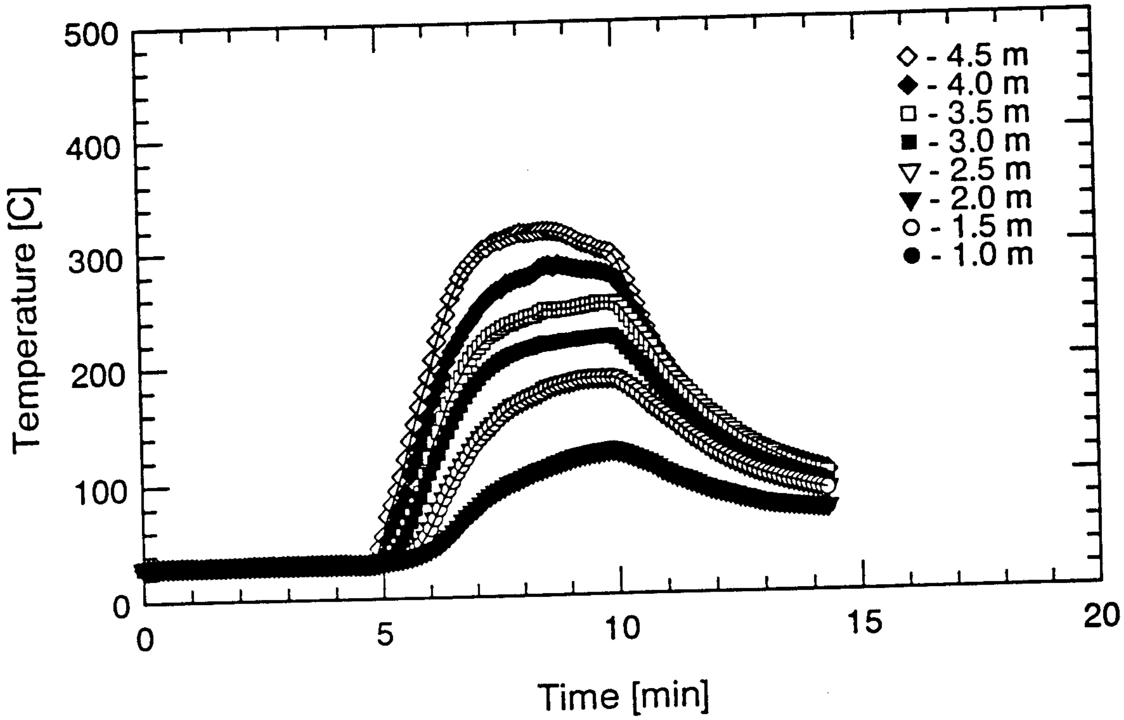

Plots: = is Maximum Protected Height, - is Minimum Protected,
+ is NFPA Calculation

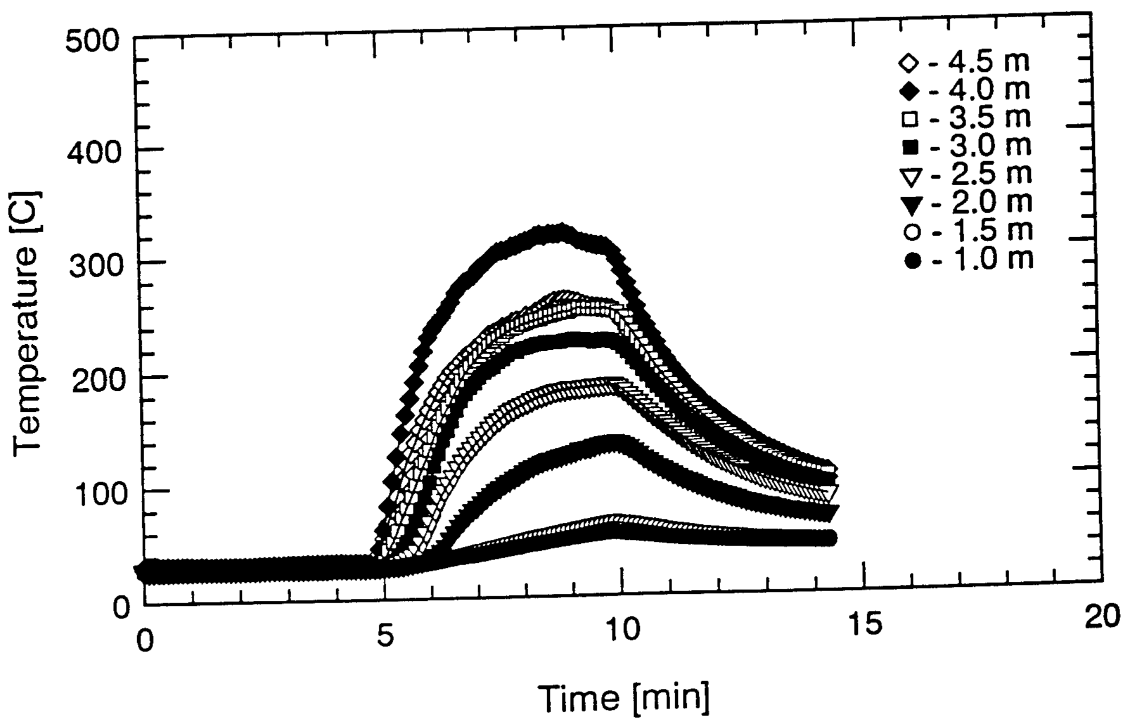
# Appendix C

## Test Data

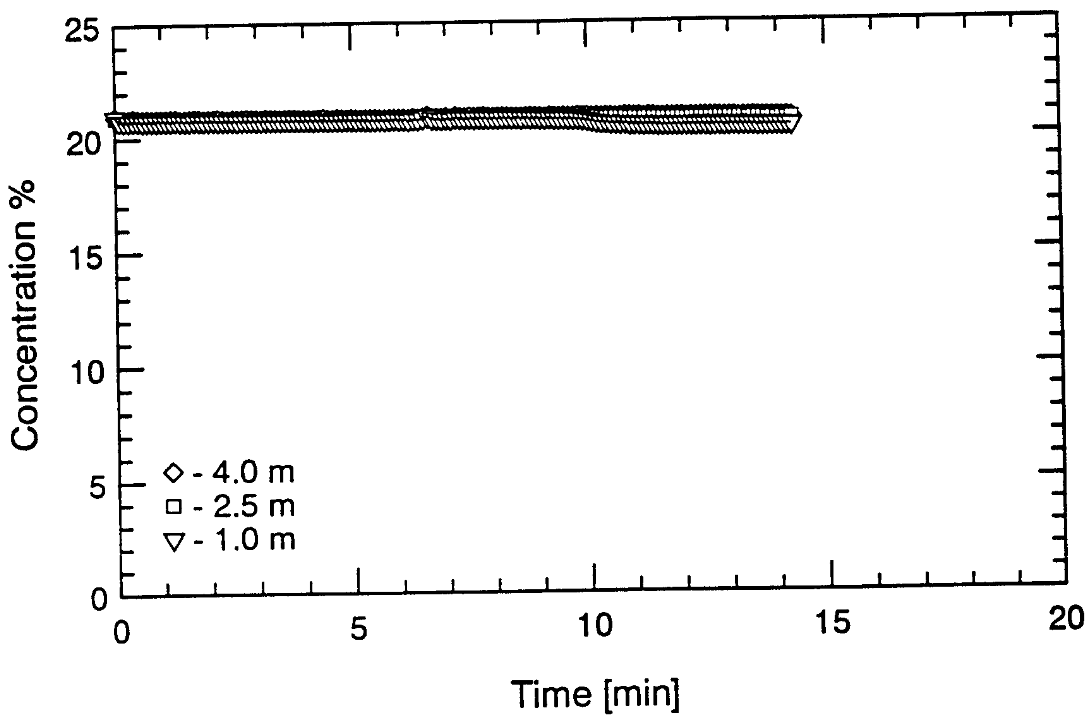
CONTENTS

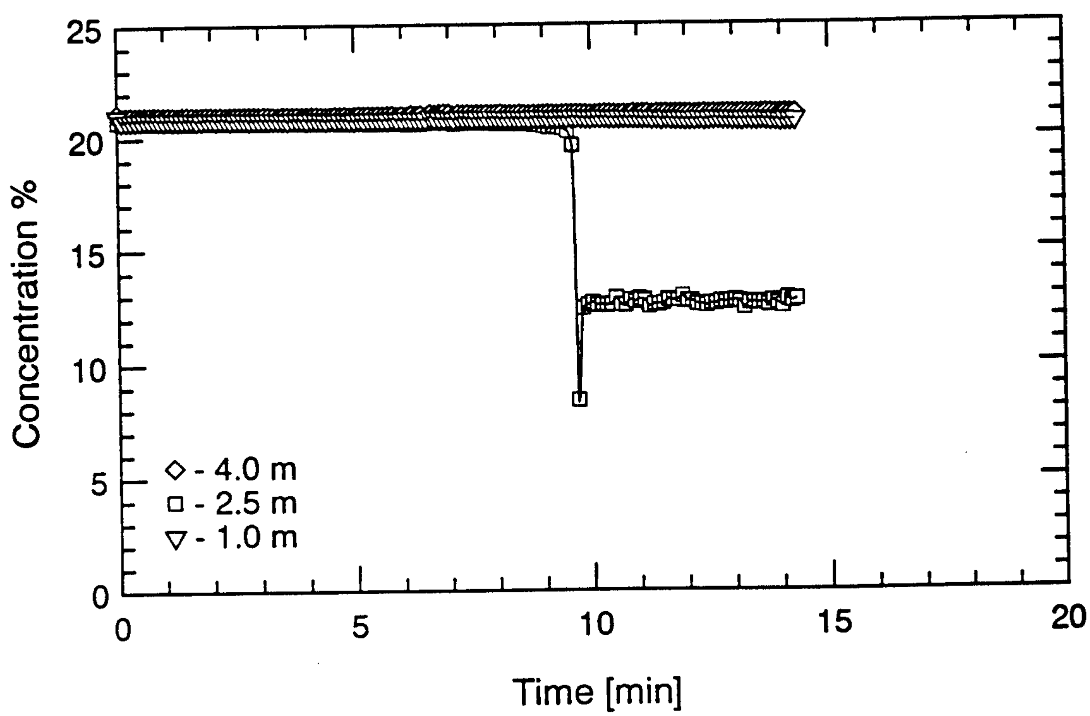
| Test | Agent | Number of Nozzles | Nozzle | Fire Scenario | Page Number |
|---|---|---|---|---|---|
| 26 | CEA-410 | 4 | N6 | 2 | C-88 |
| 27 | CEA-410 | 4 | N6 | 4 | C-92 |
| 28 | CEA-410 | 4 | N6 | 3 | C-96 |
| 29 | CEA-410 | 4 | N6 | 2A | C-100 |
| 30 | CEA-410 | 4 | N6 | 4A | C-104 |
| 31 | CEA-410 | 4 | N6 | 3A | C-108 |
| 32 | CEA-410 | 4 | N6 | 3B | C-112 |
| 33 | FM-200 | 4 | N7 | 1 | C-116 |
| 34 | FM-200 | 4 | N7 | 2 | C-120 |
| 35 | FM-200 | 4 | N7 | 2A | C-124 |
| 36 | FM-200 | 4 | N7 | 4A | C-128 |
| 37 | FM-200 | 4 | N7 | 4 | C-132 |
| 38 | FM-200 | 4 | N7 | 3A | C-136 |
| 39 | FM-200 | 4 | N7 | 3B | C-140 |
| 40 | FM-200 | 4 | N7 | 3 | C-144 |
| 41 | FM-200 | 4 | N7 | 2 | C-148 |
| 42 | Envirogel | 2 | N8 | 1 | C-152 |
| 43 | Envirogel | 2 | N9 | 1 | C-156 |
| 44 | Envirogel | 2 | N9 | 1 | C-160 |
| 45 | Envirogel | 2 | N9 | 1 | C-164 |
| 46 | Envirogel | 2 | N9 | 3B | C-168 |



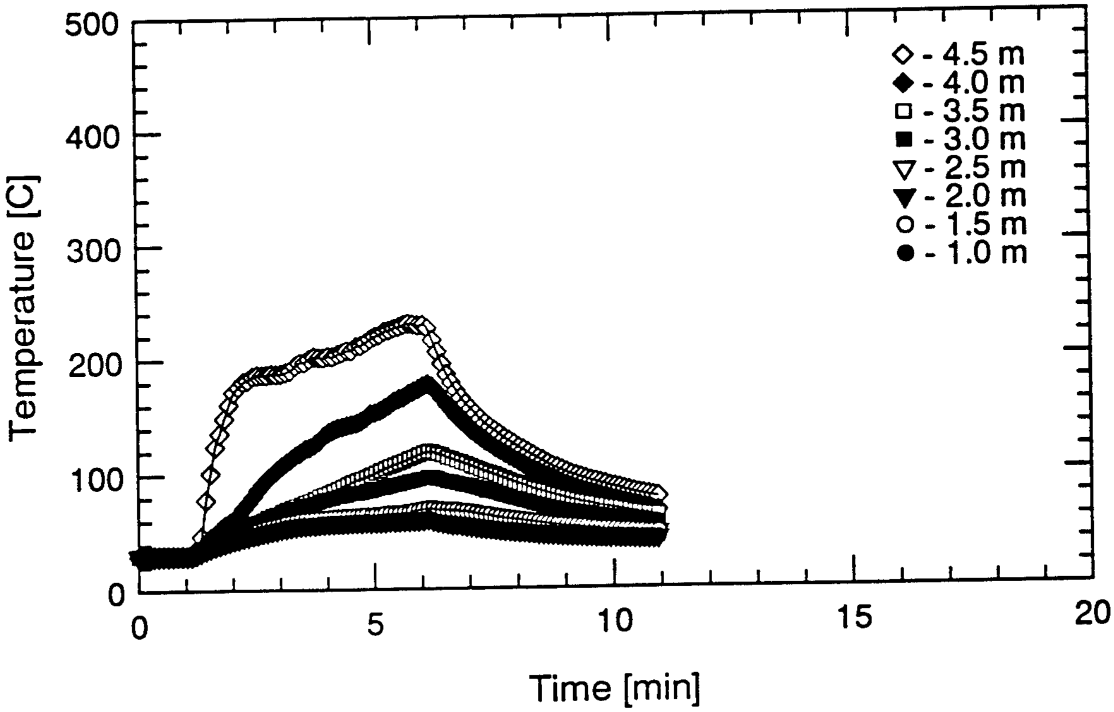



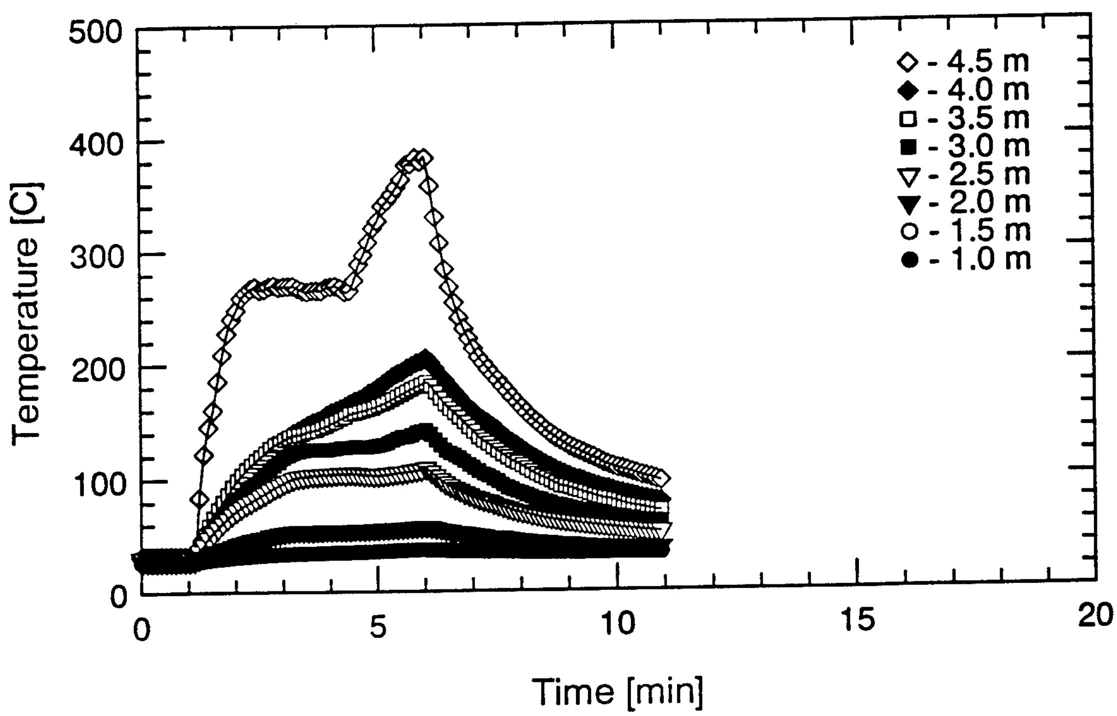

Compartment Temperatures
TEST #1



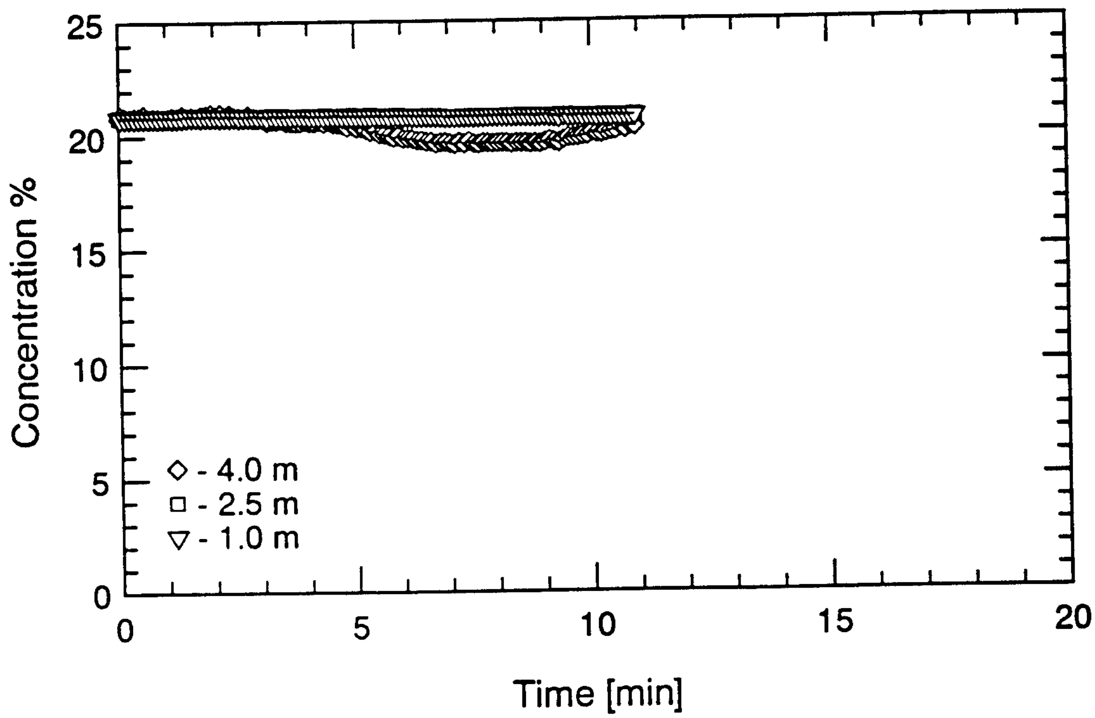



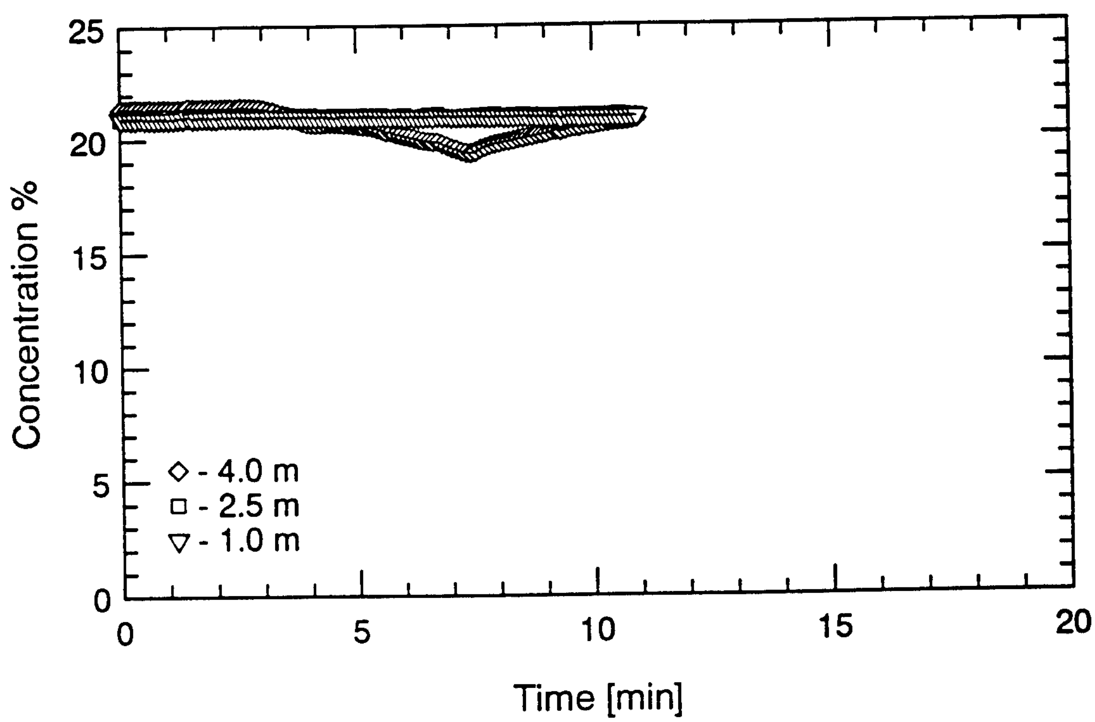

Oxygen Concentrations
TEST #1




Compartment Temperatures
TEST #2




Oxygen Concentrations
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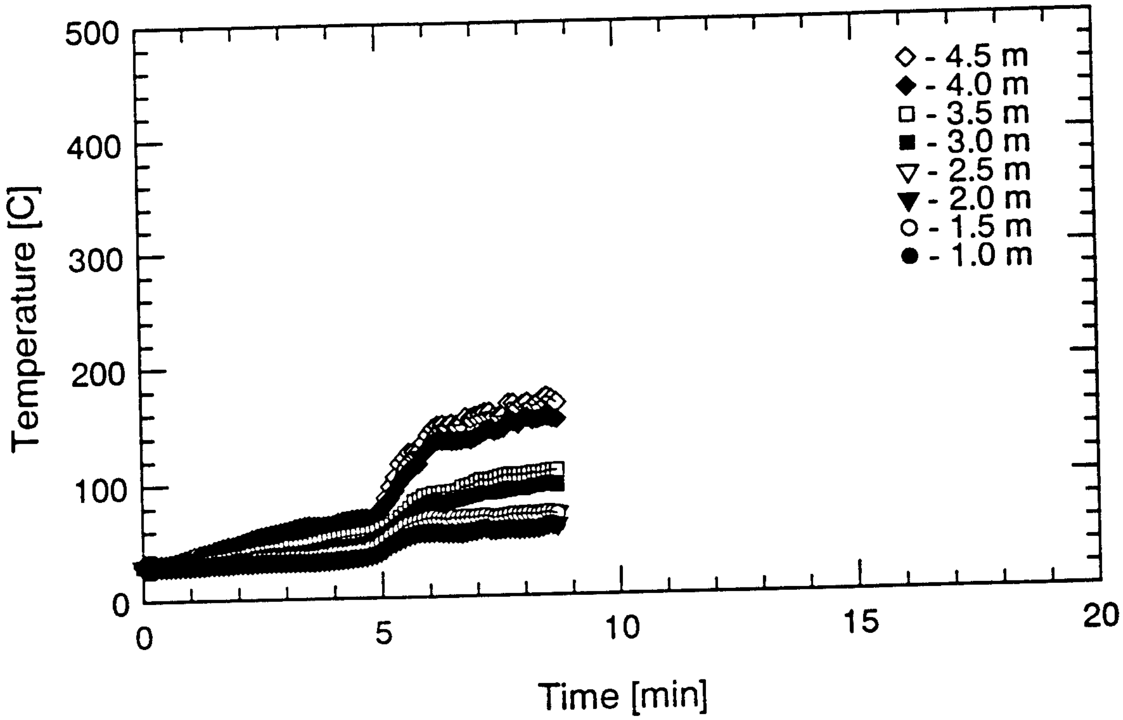


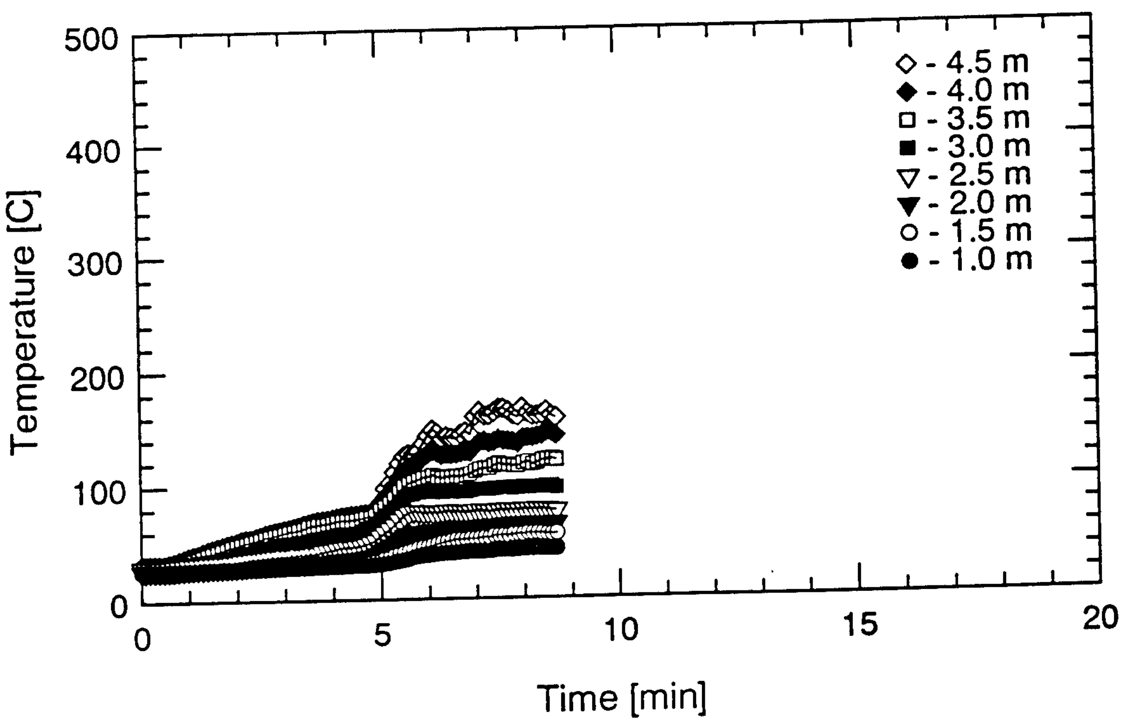


Compartment Temperatures
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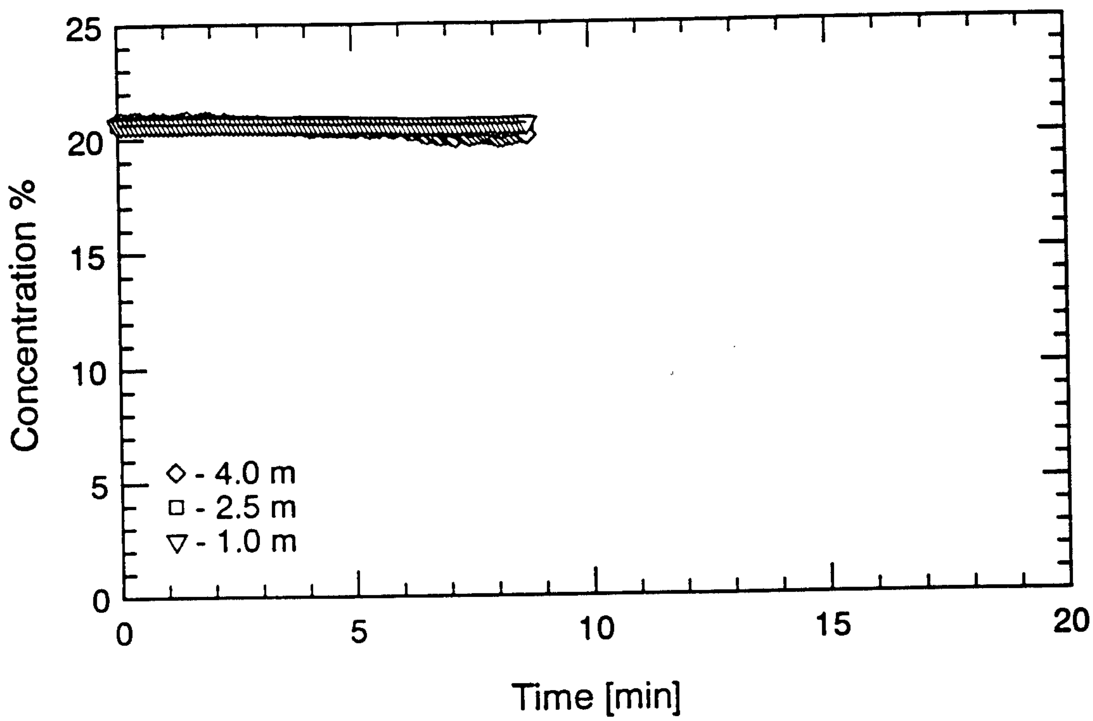


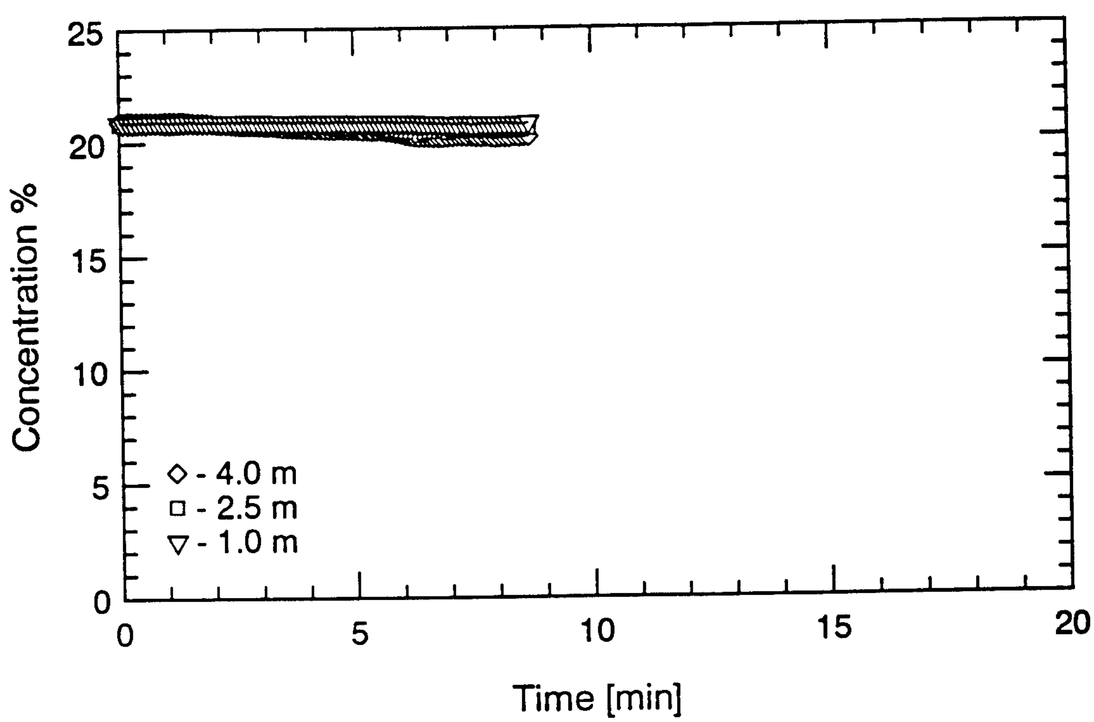


Oxygen Concentrations
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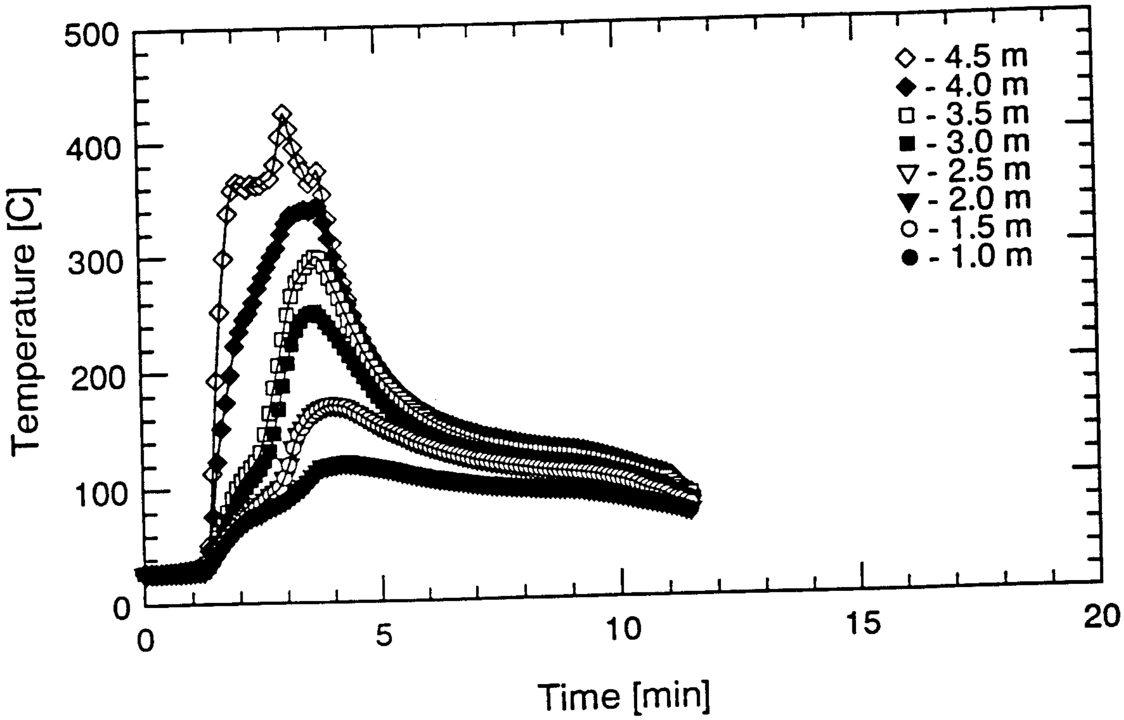


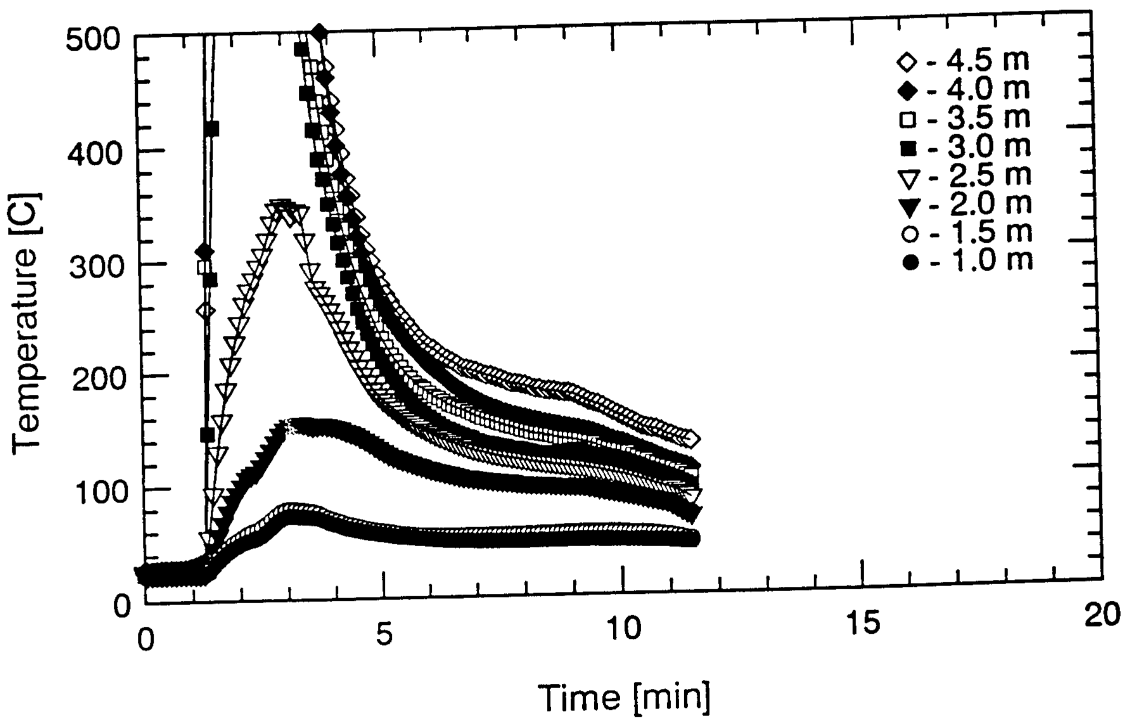


Compartment Temperatures
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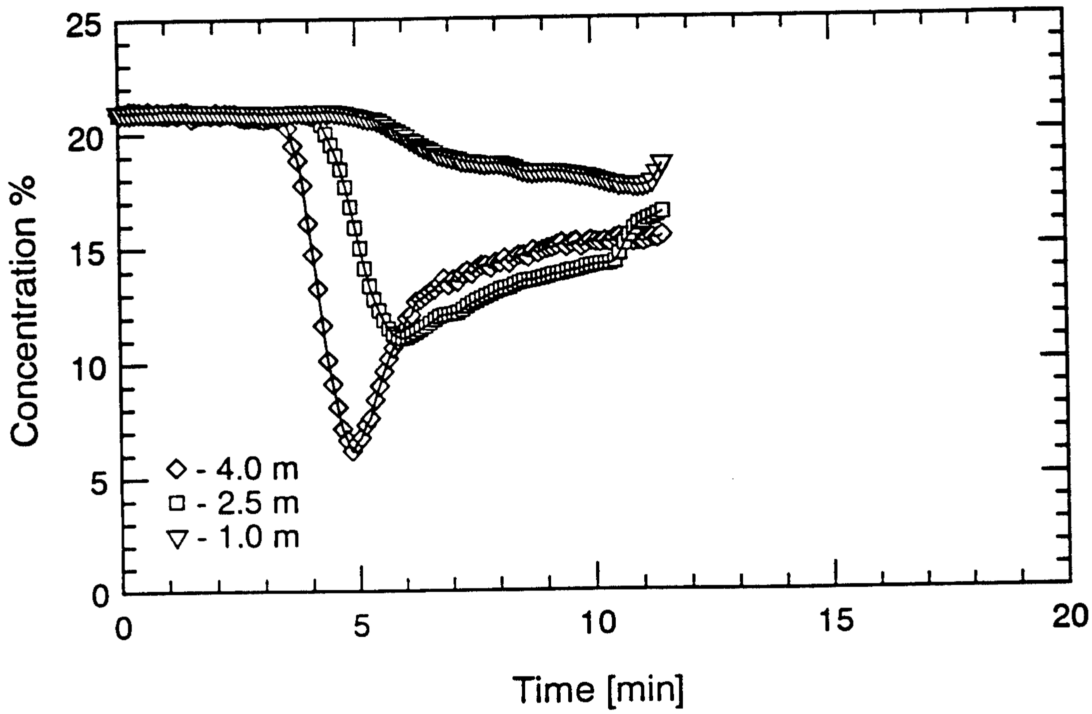
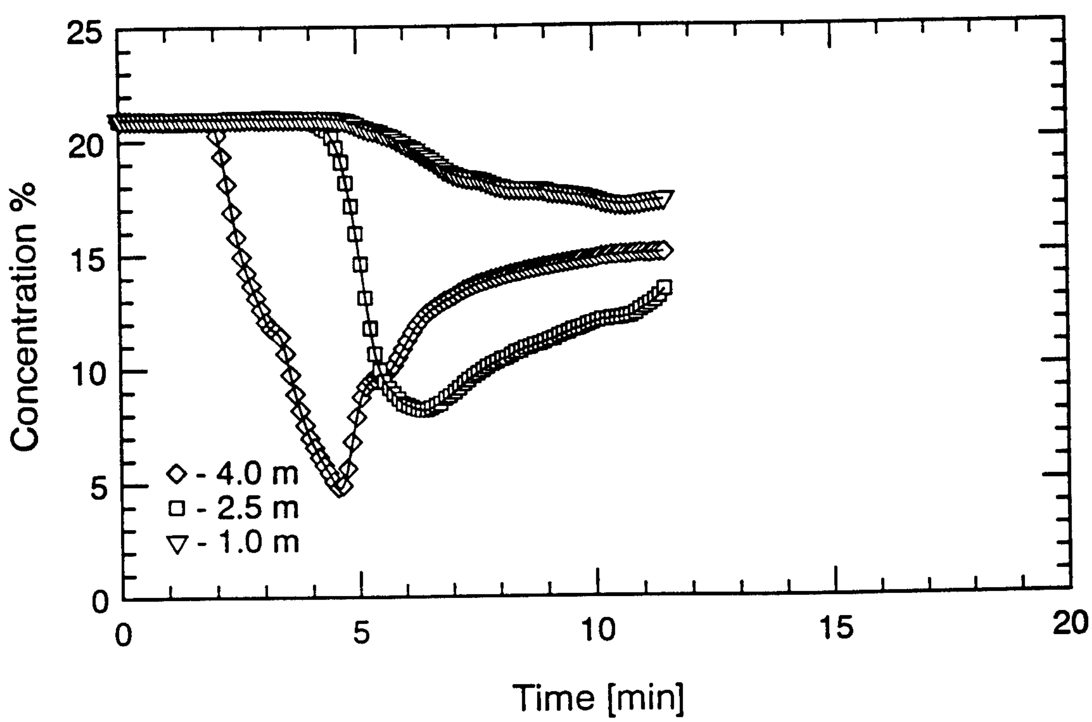
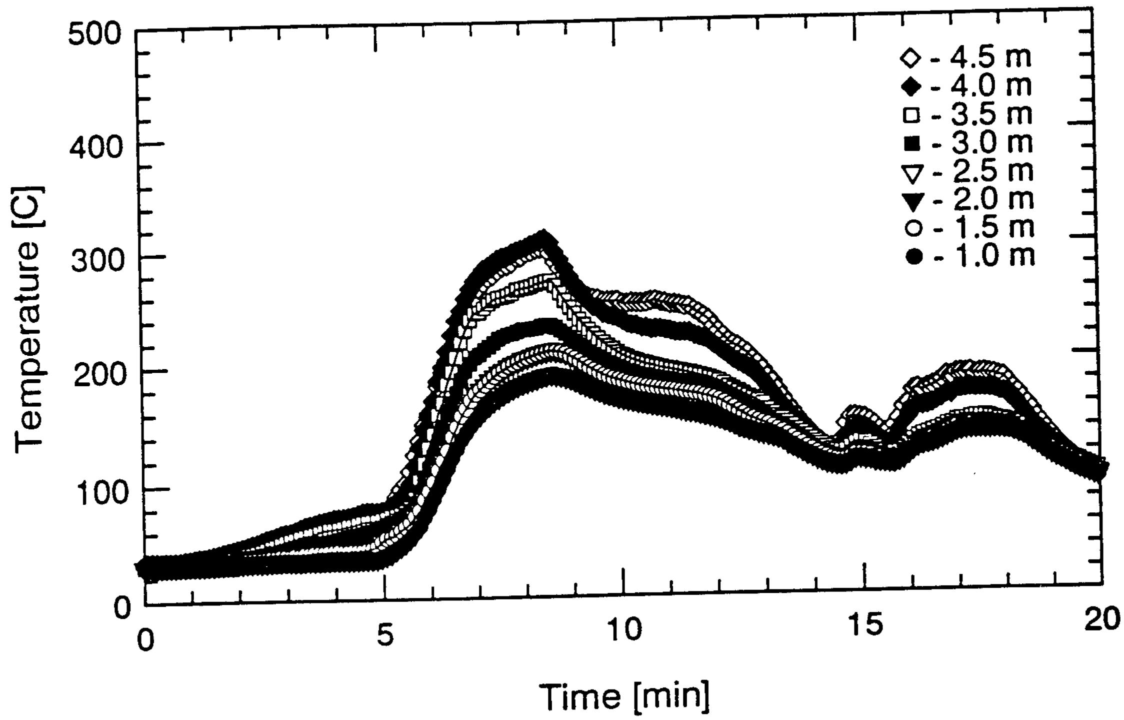
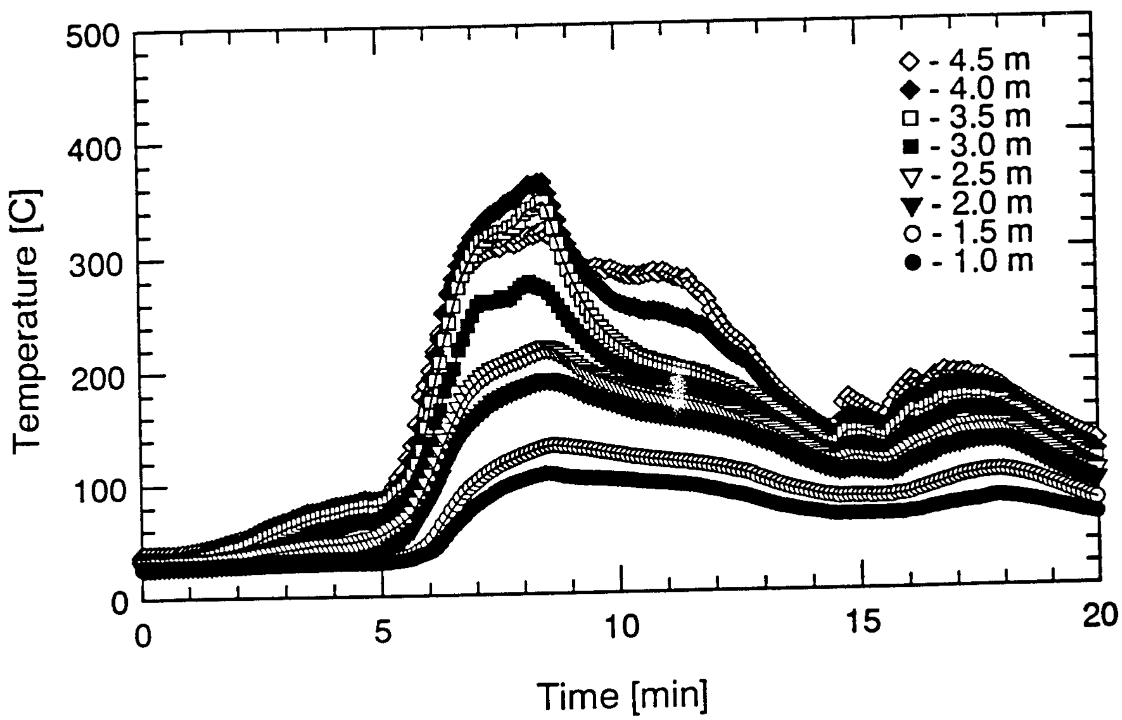



Oxygen Concentrations
TEST #4




Compartment Temperatures
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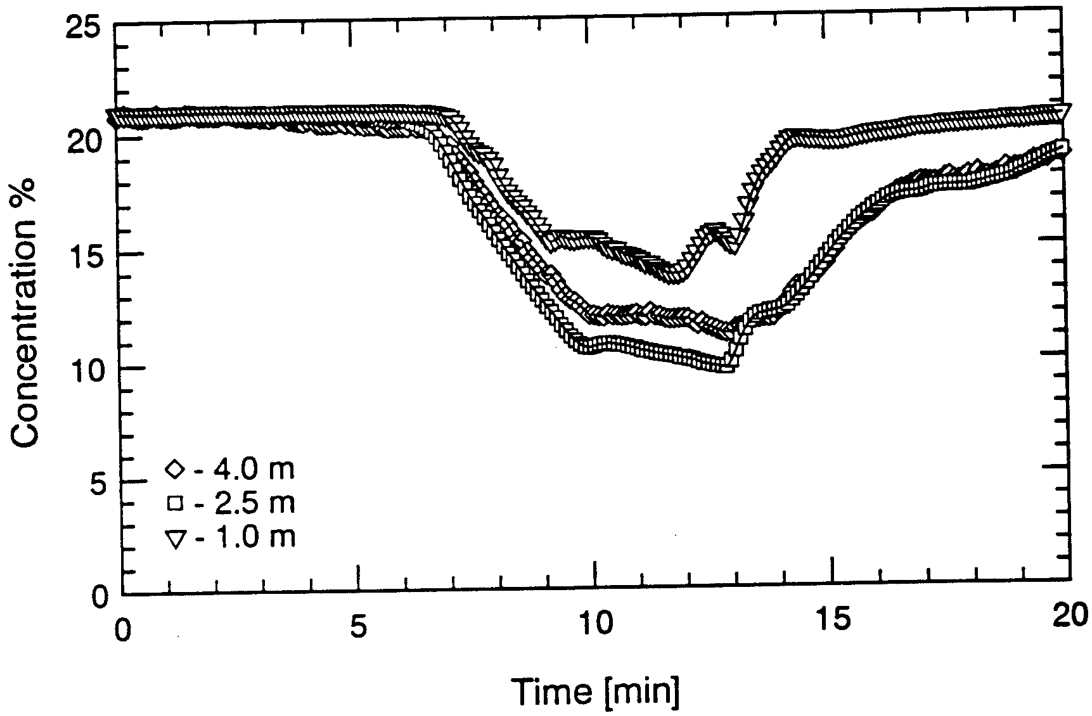
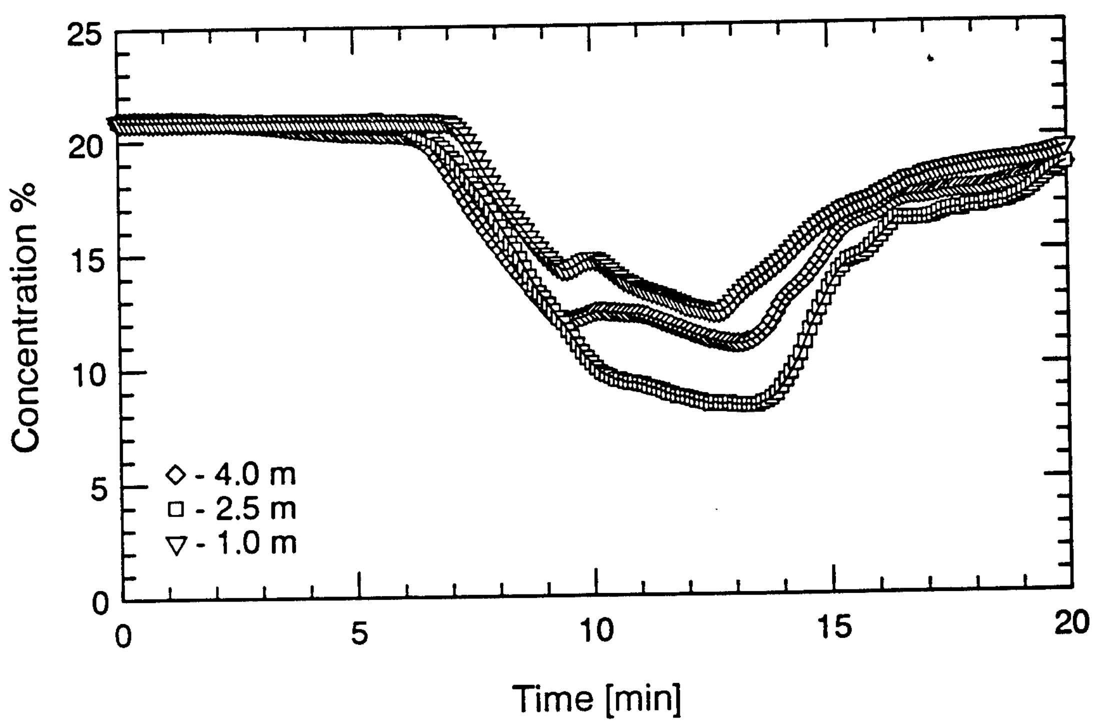
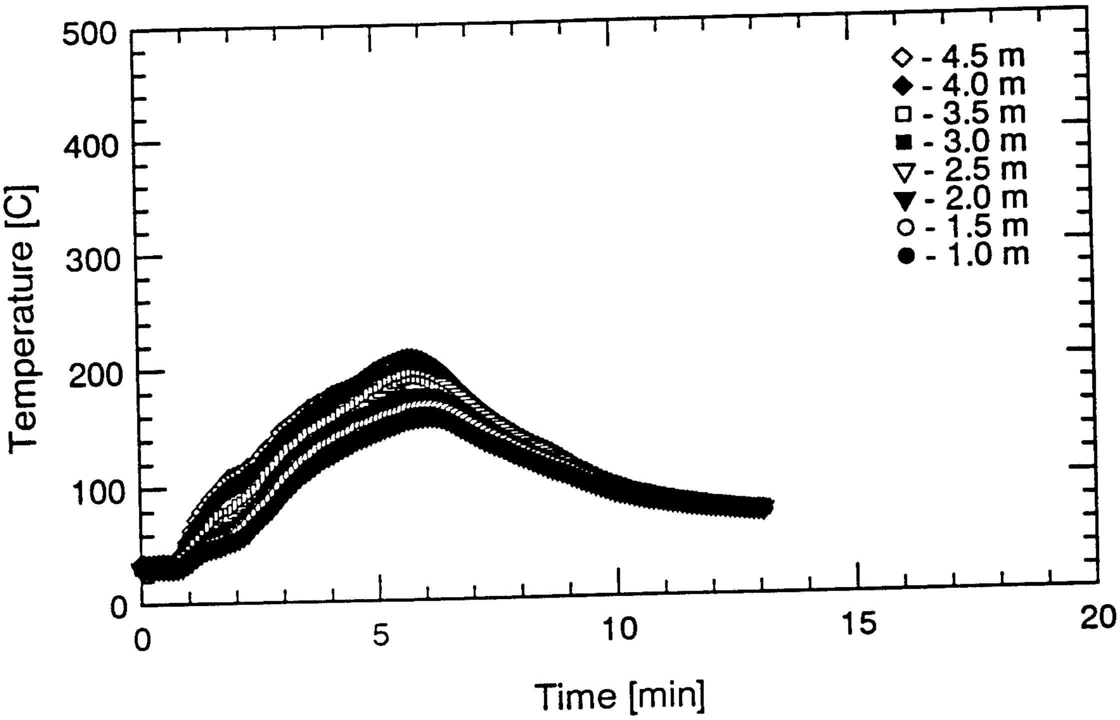
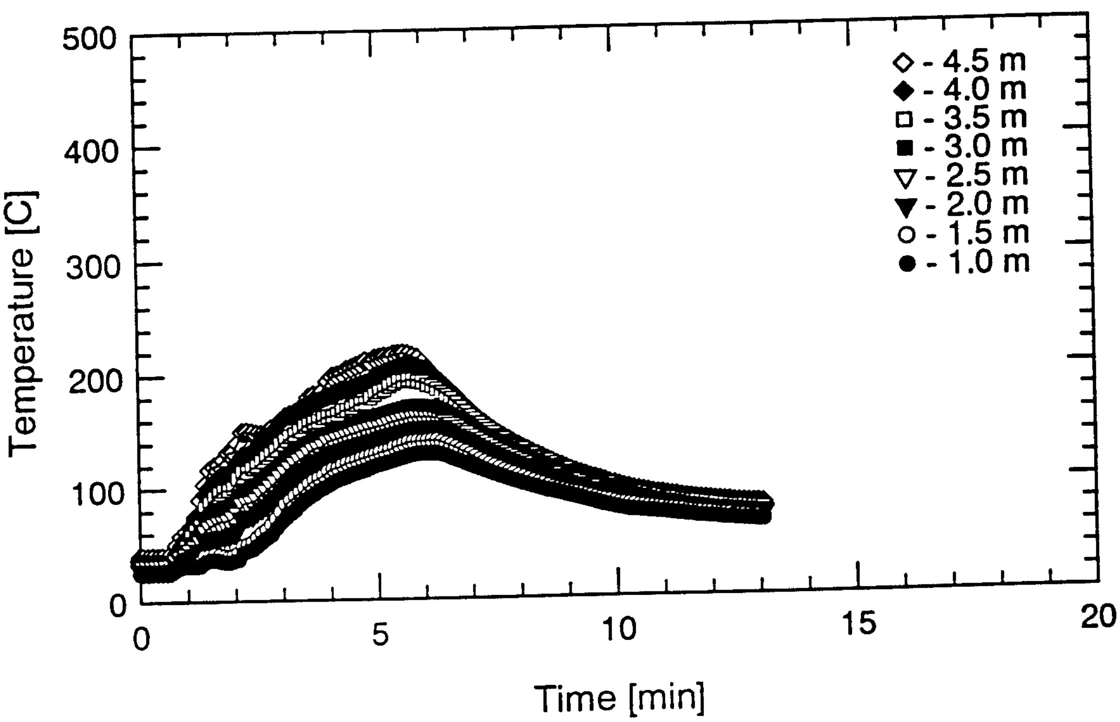



Oxygen Concentrations
TEST #5




Compartment Temperatures
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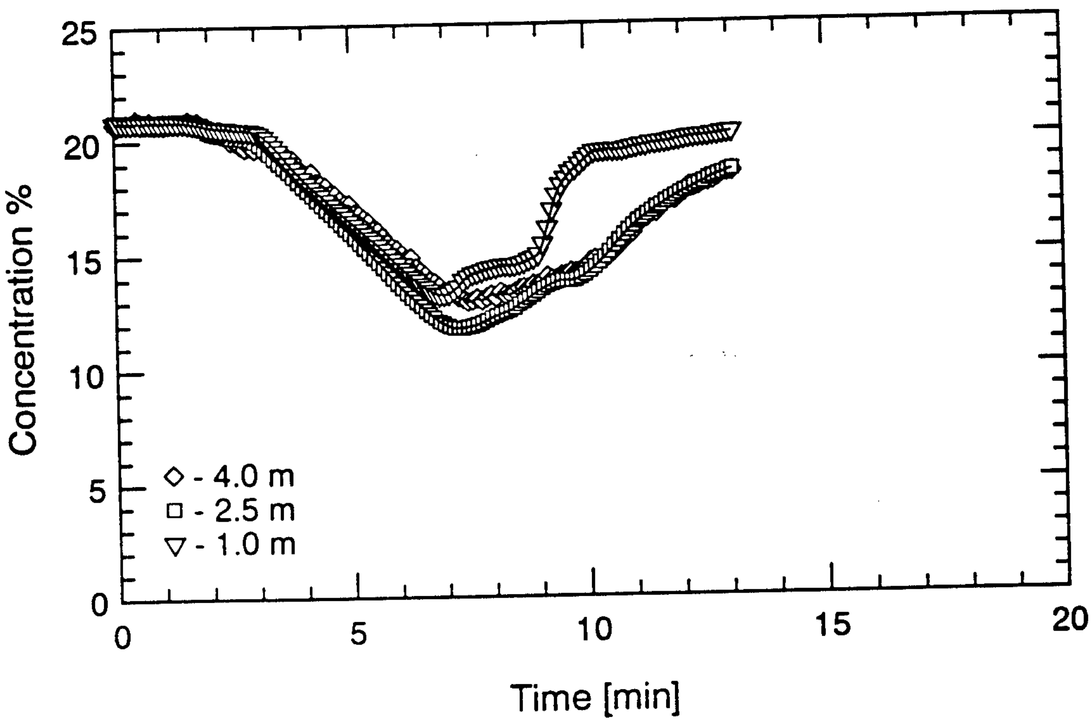
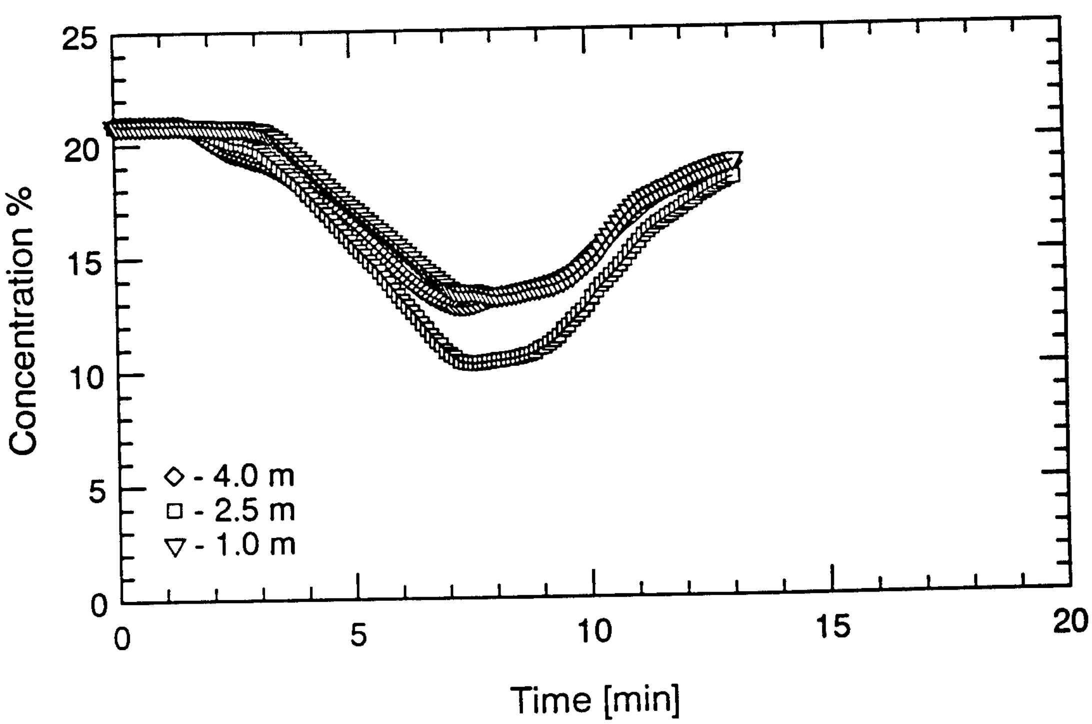
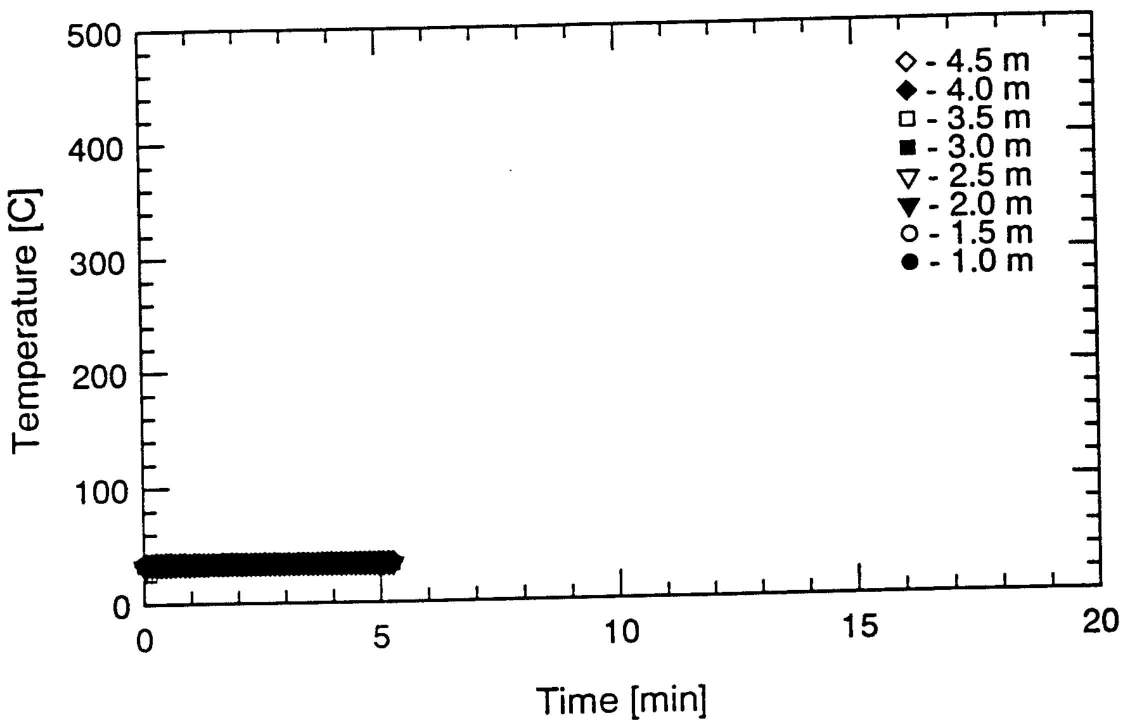
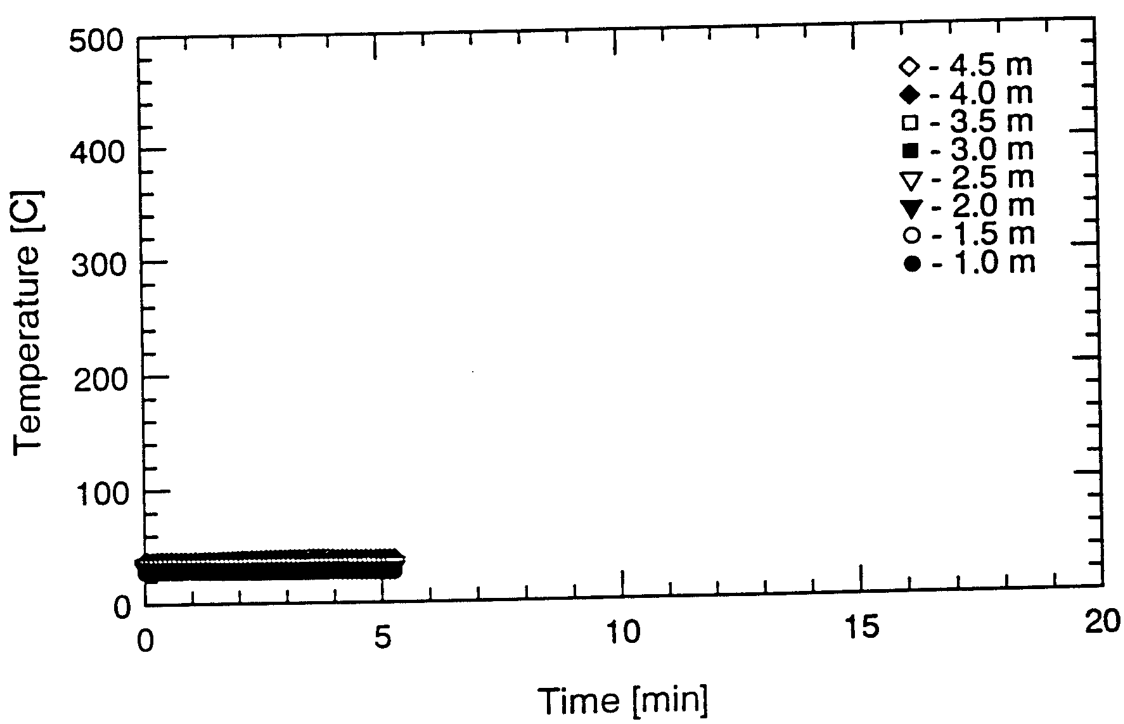



Oxygen Concentrations
TEST #6




Compartment Temperatures
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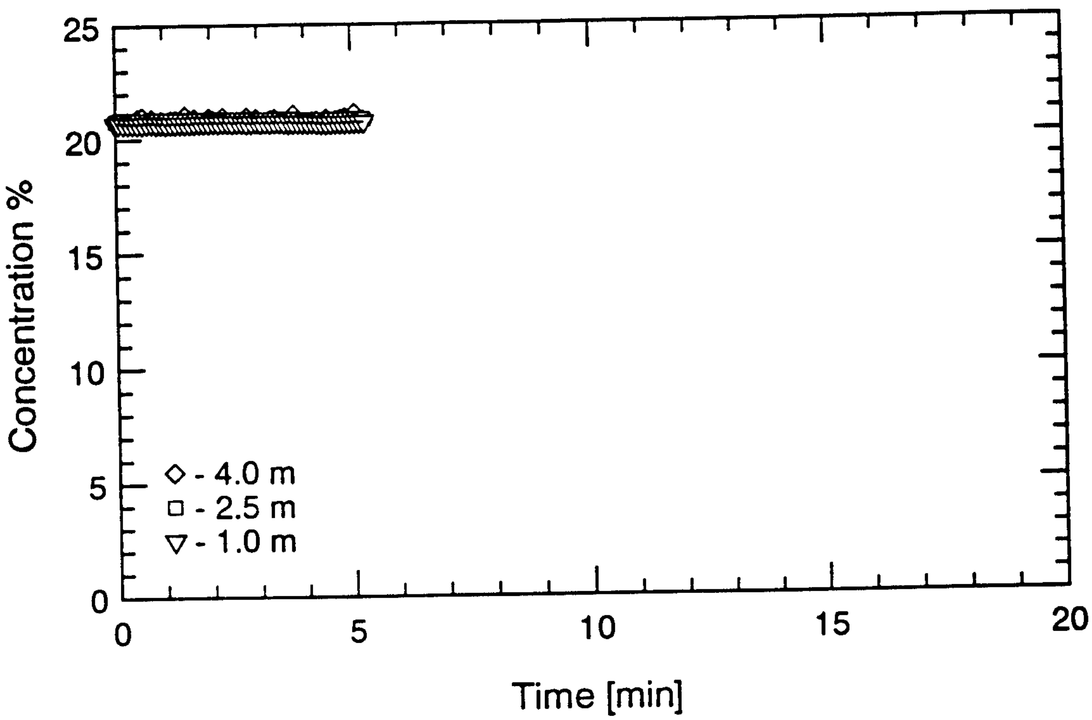
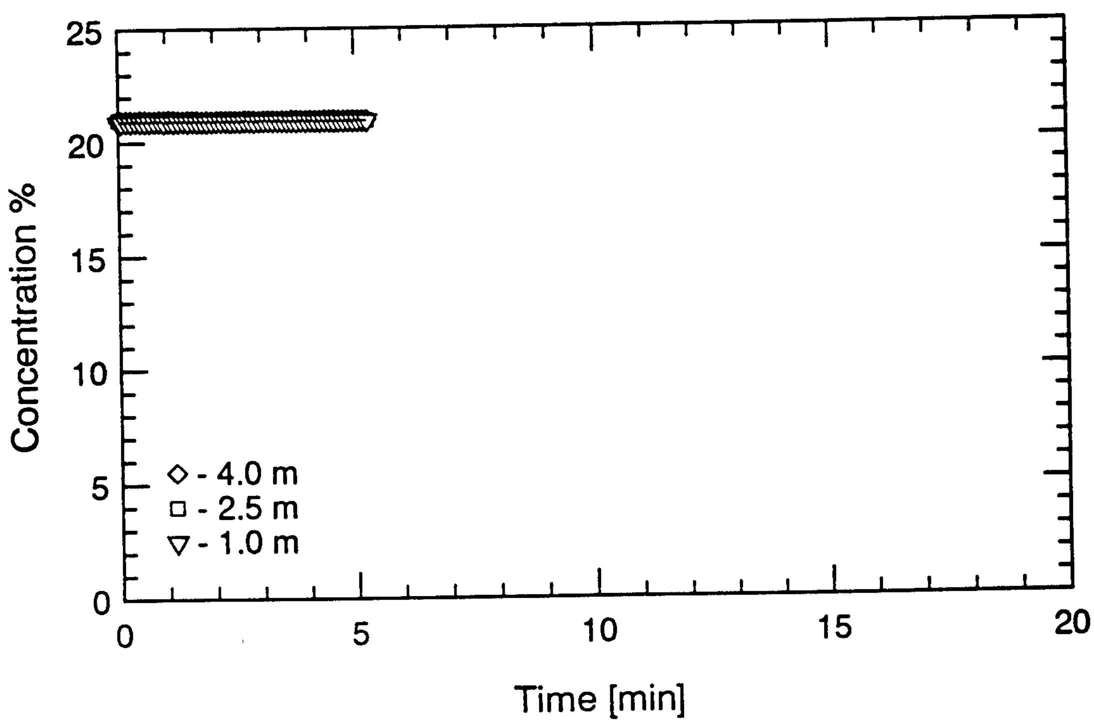
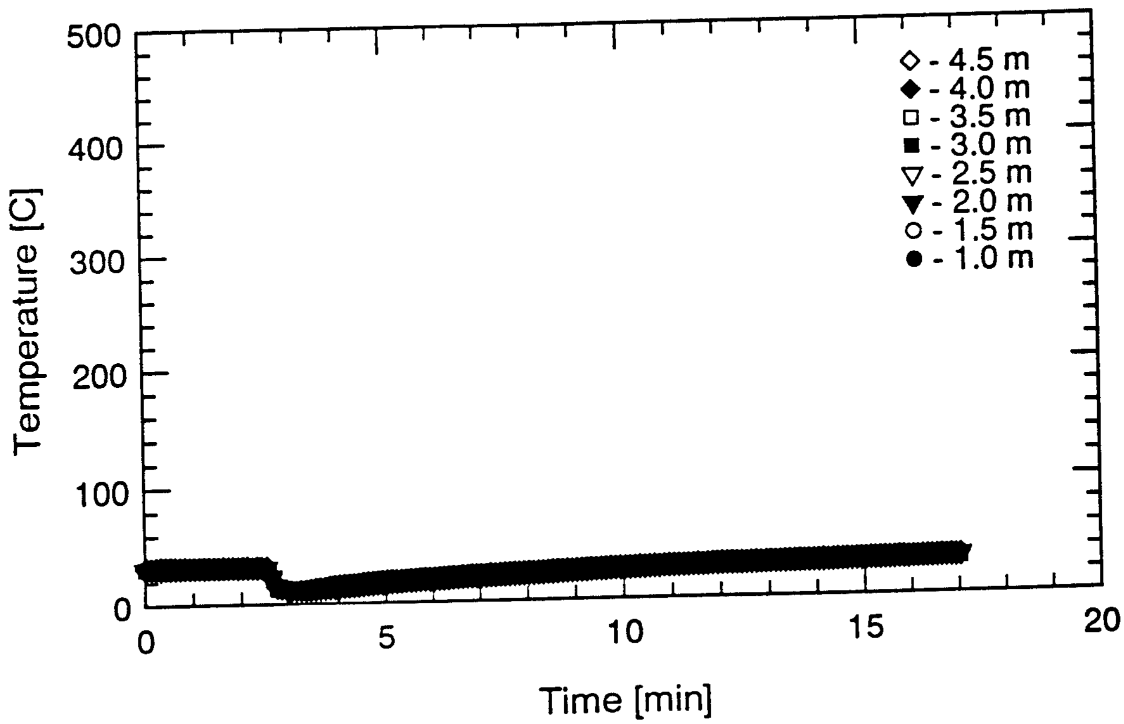
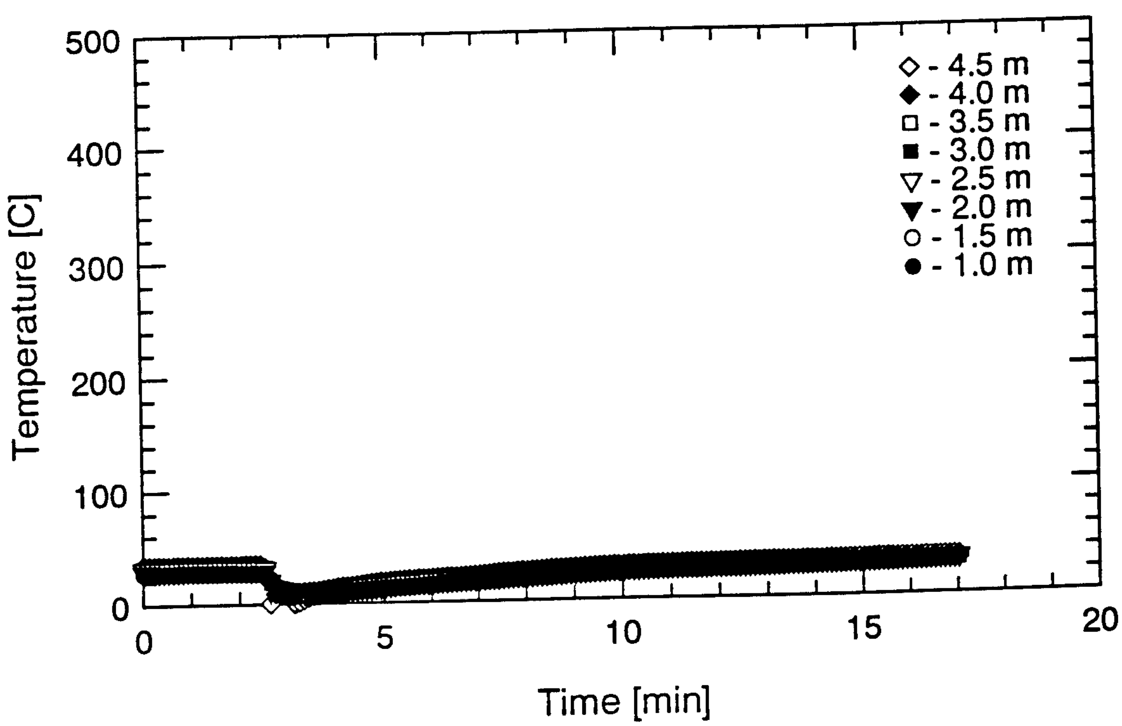



Oxygen Concentrations
TEST #7




Compartment Temperatures
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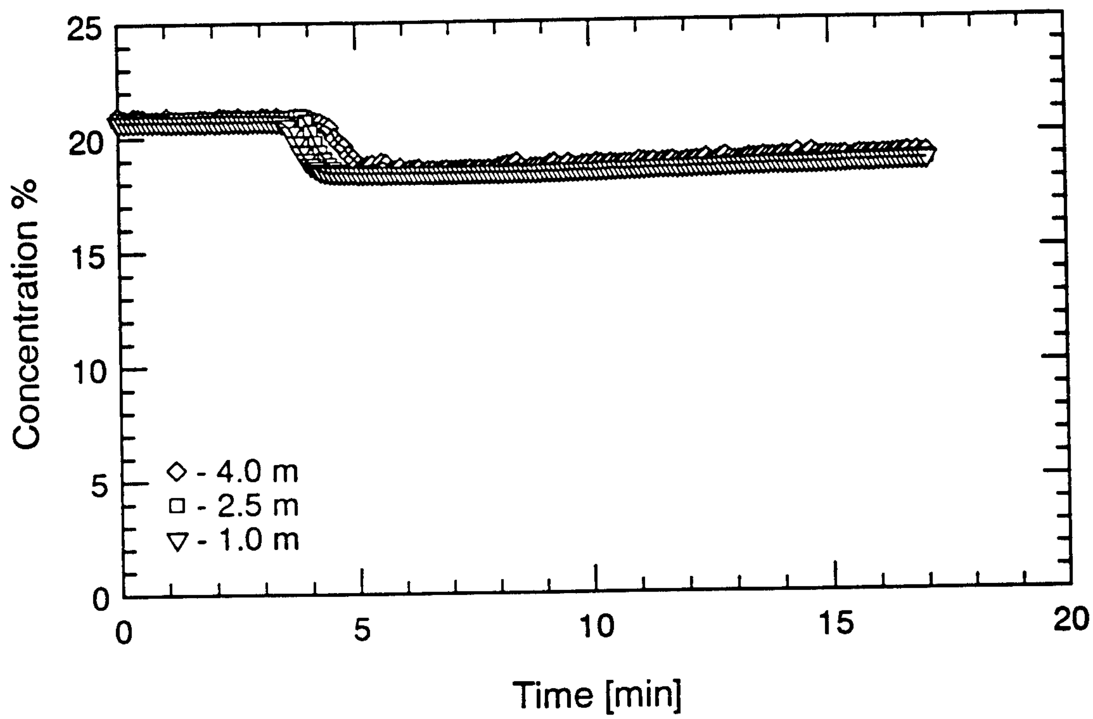
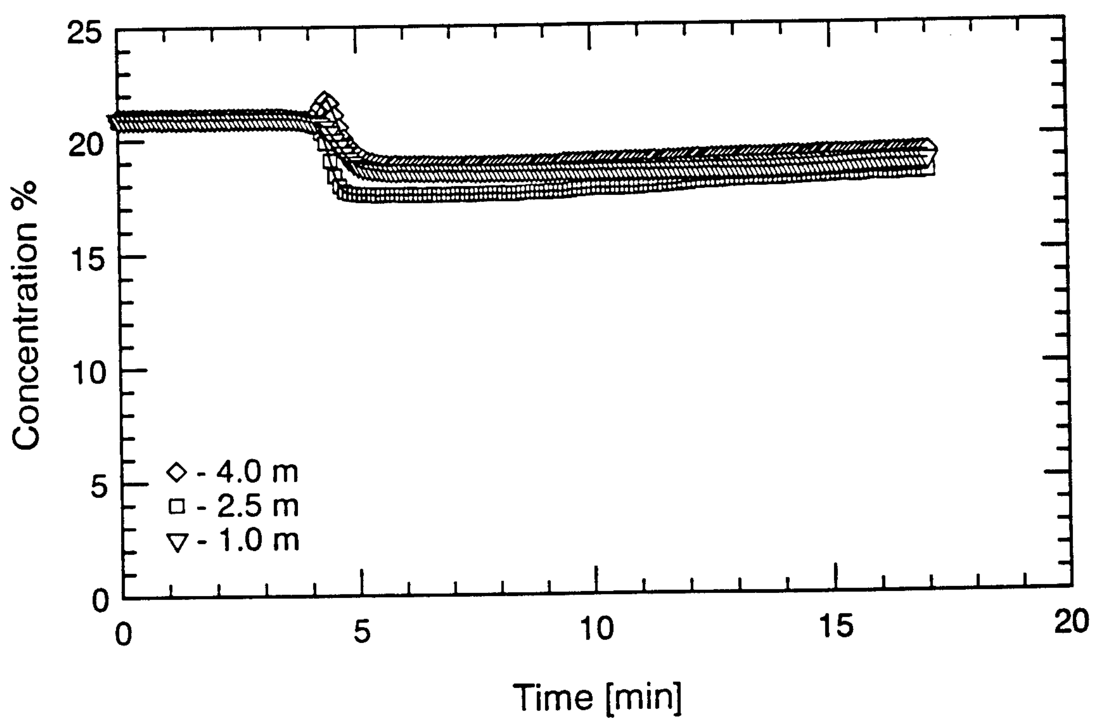
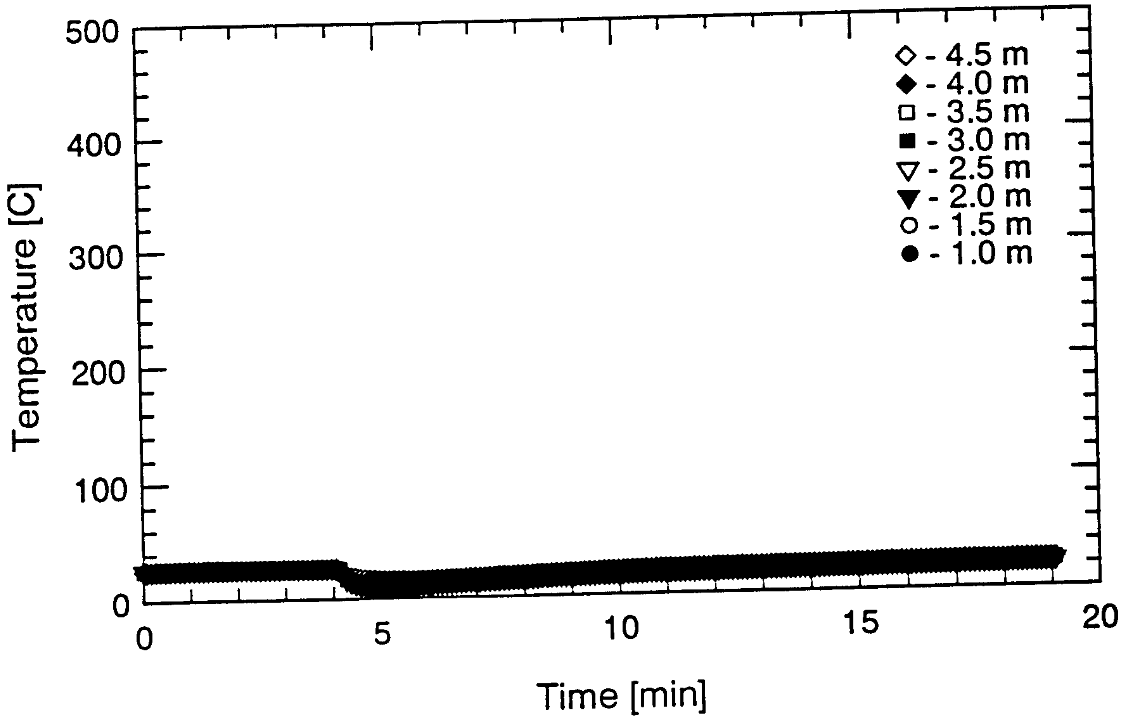
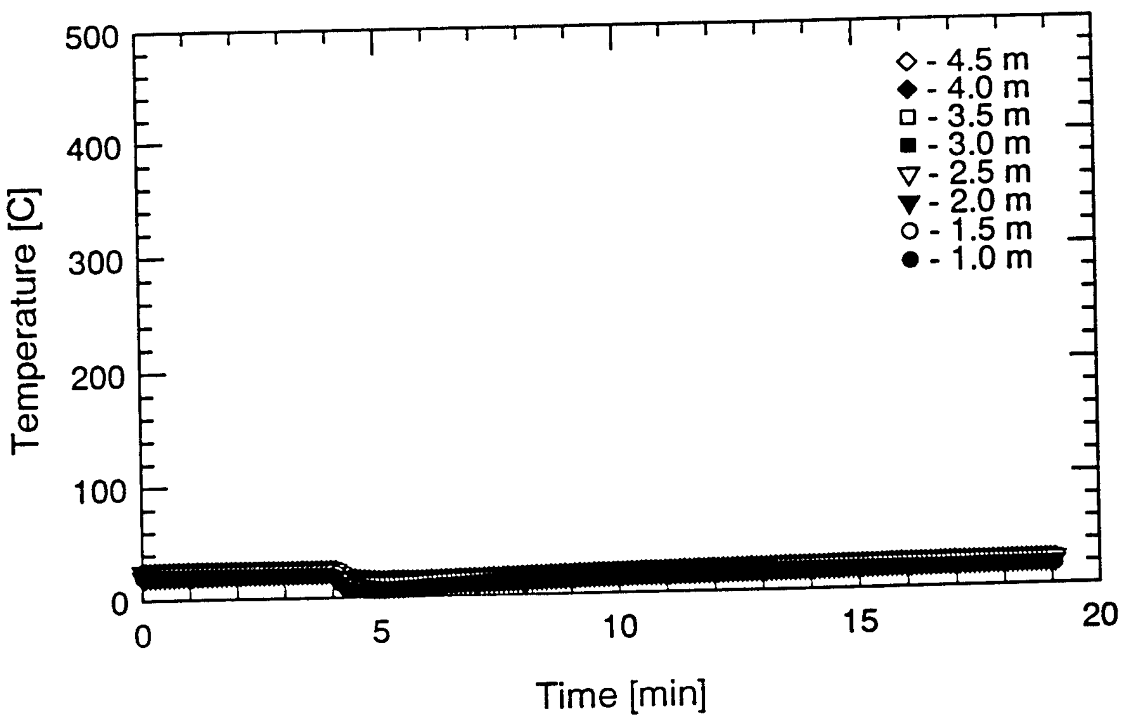


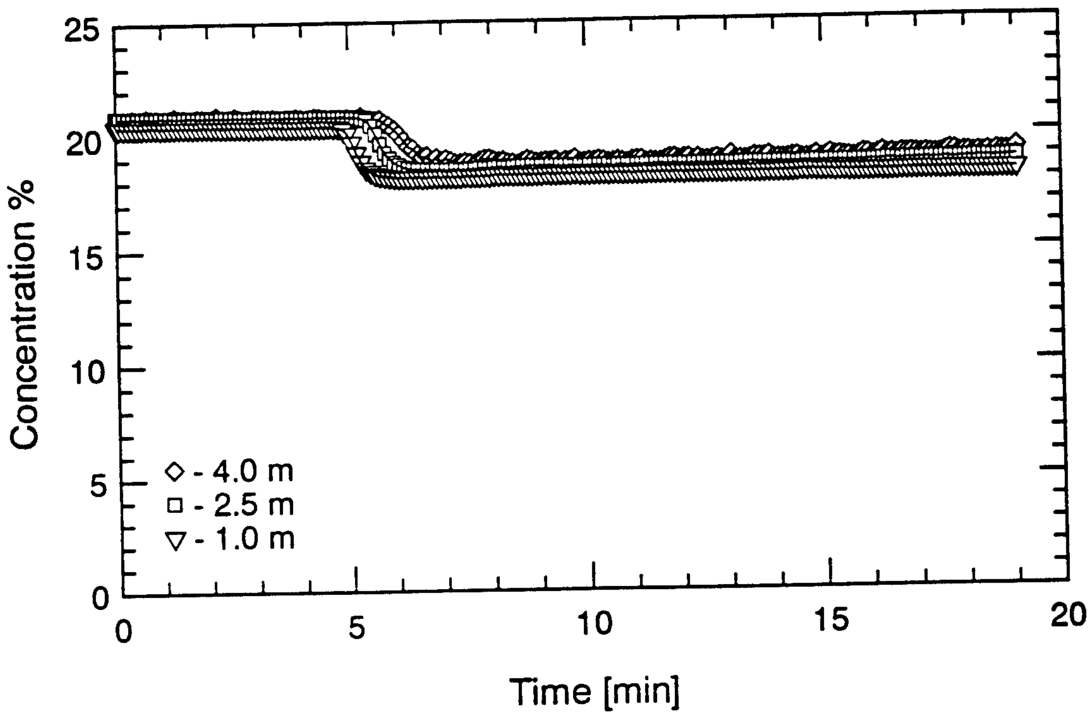



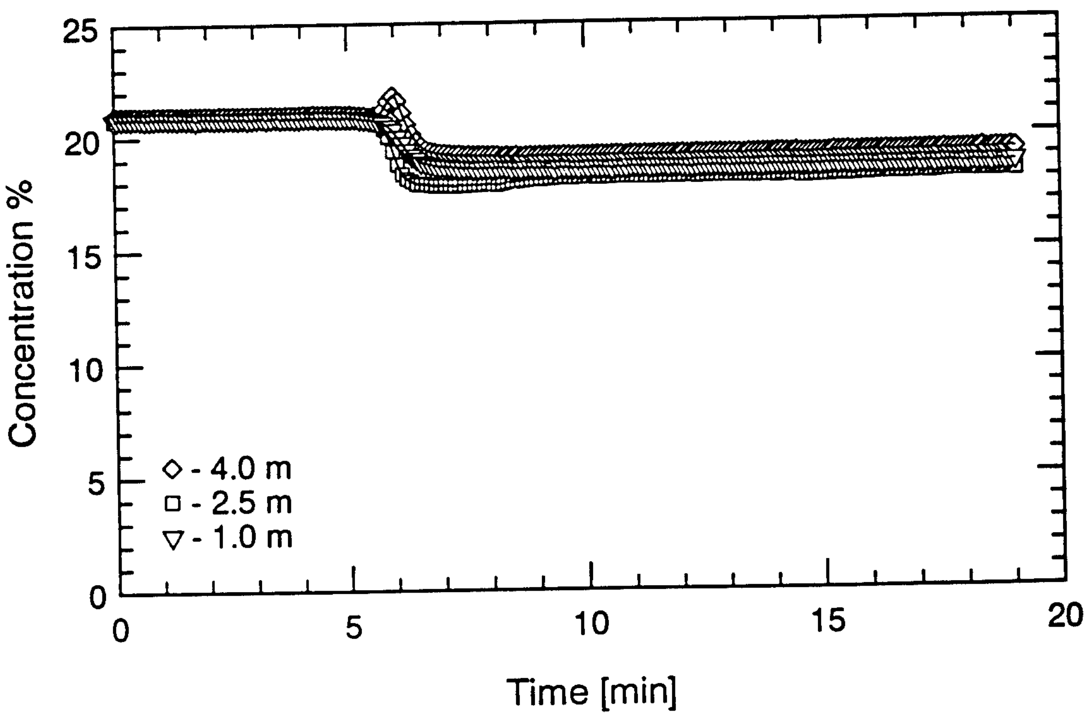

Oxygen Concentrations
TEST #8



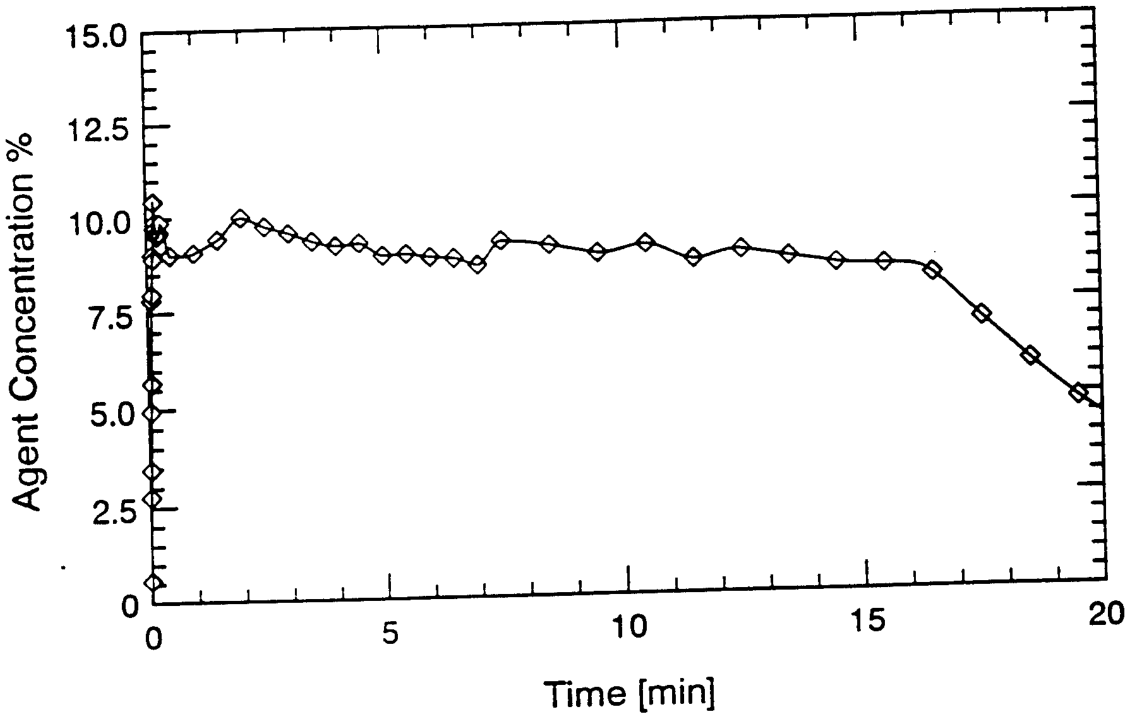



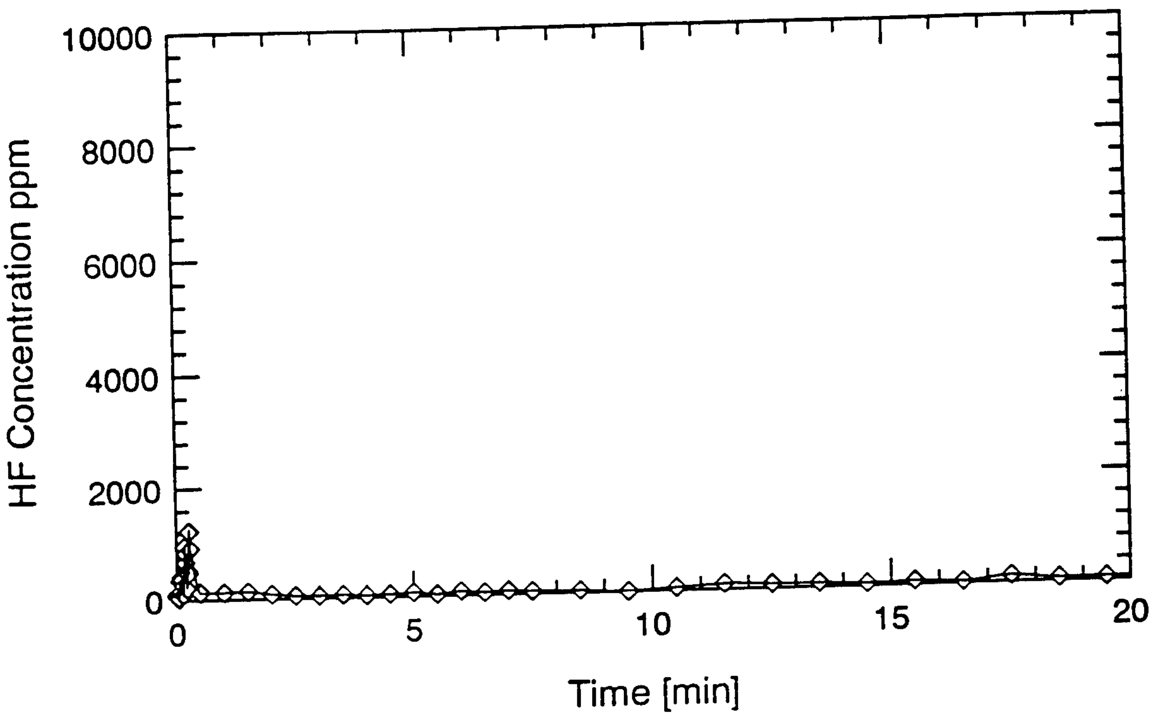

Compartment Temperatures
TEST #9



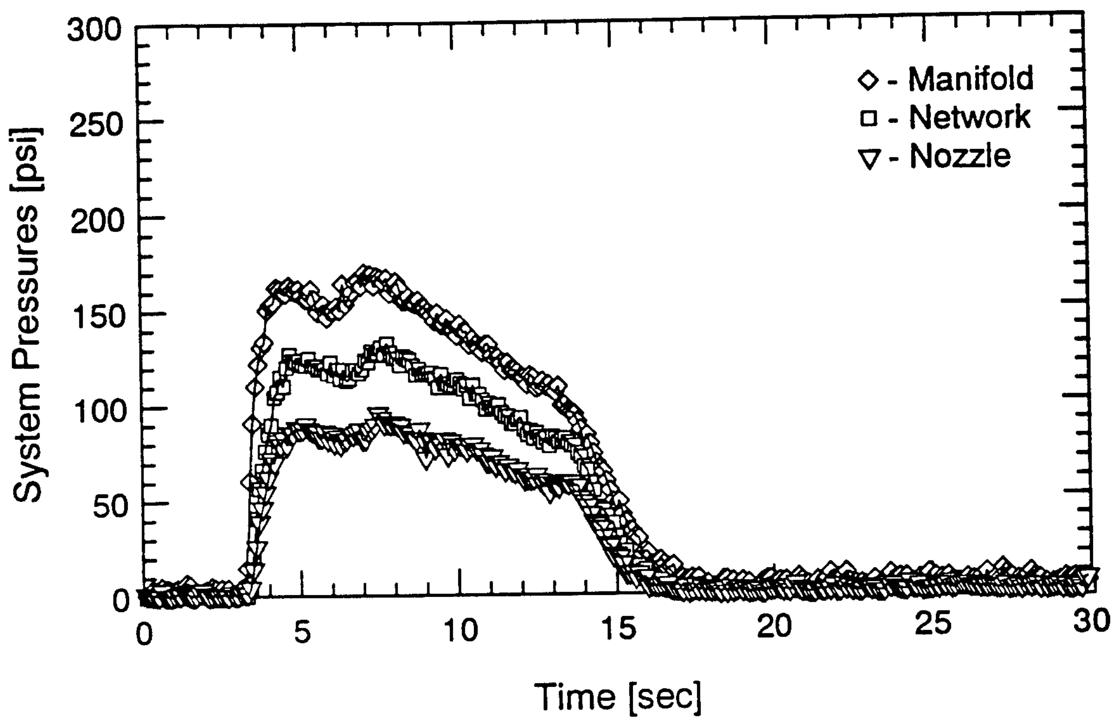



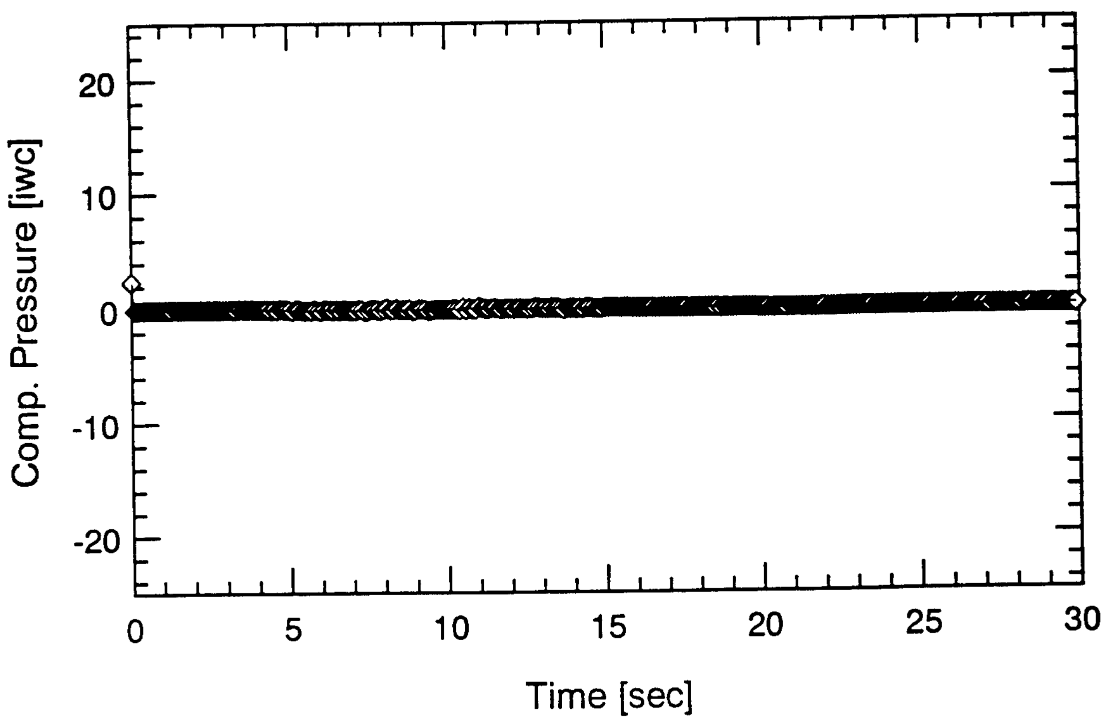

Oxygen Concentrations
TEST #9



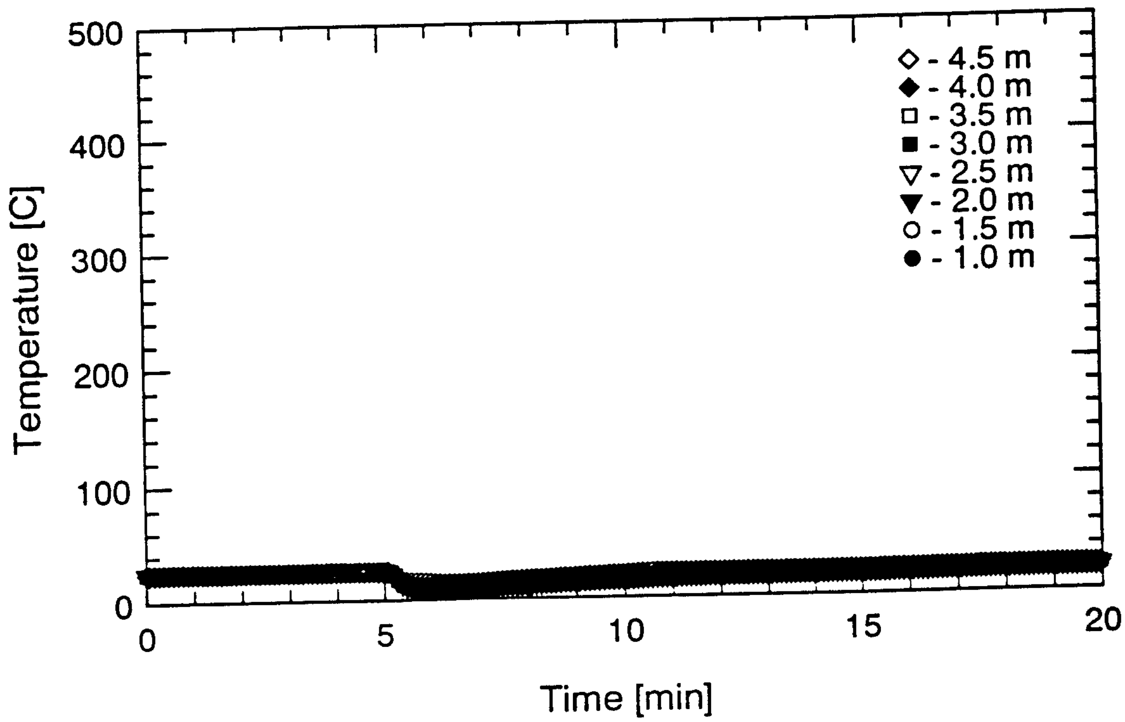



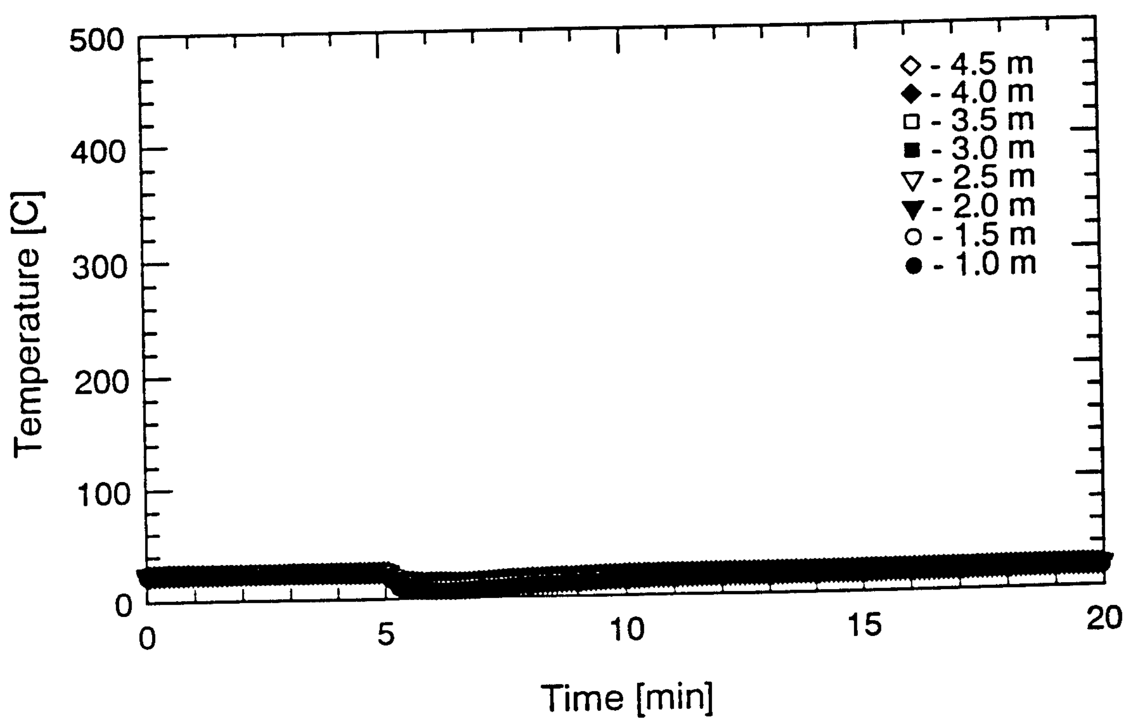

Agent and HF Concentrations
TEST #9



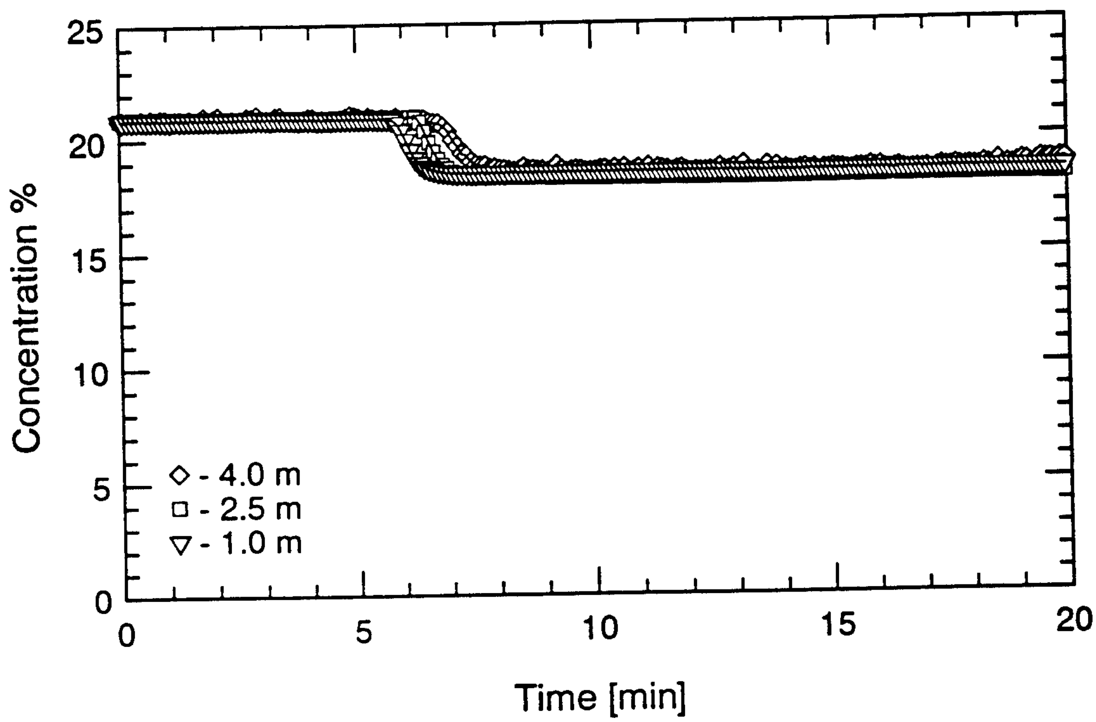



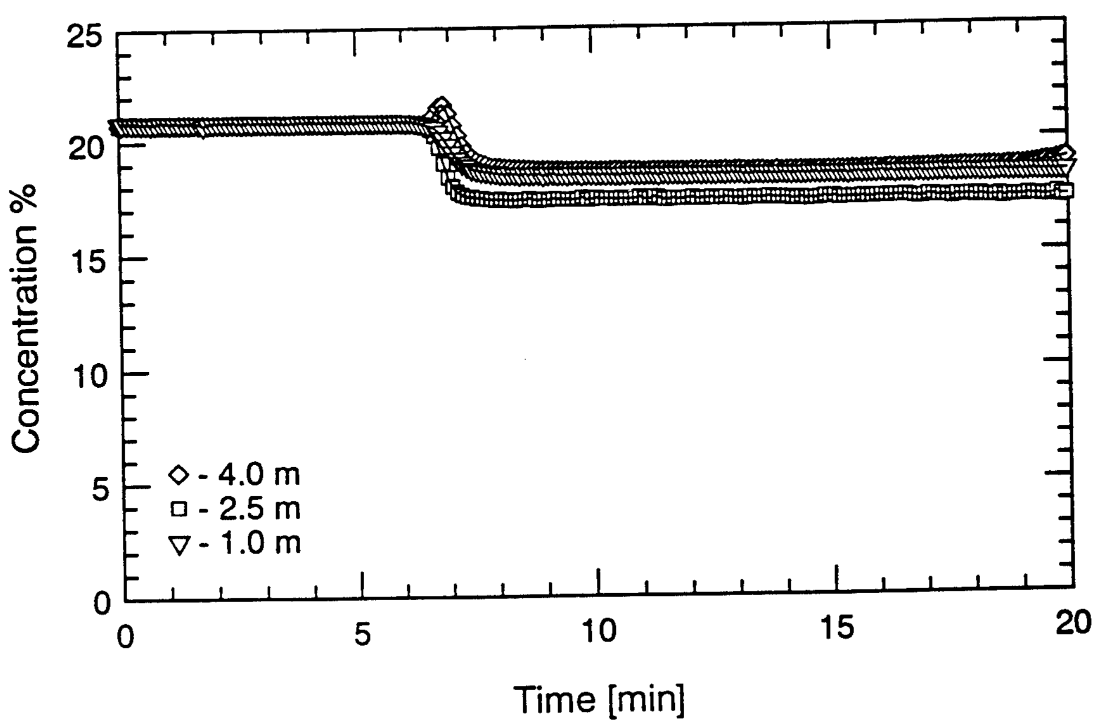

Pressure Measurements
TEST #9



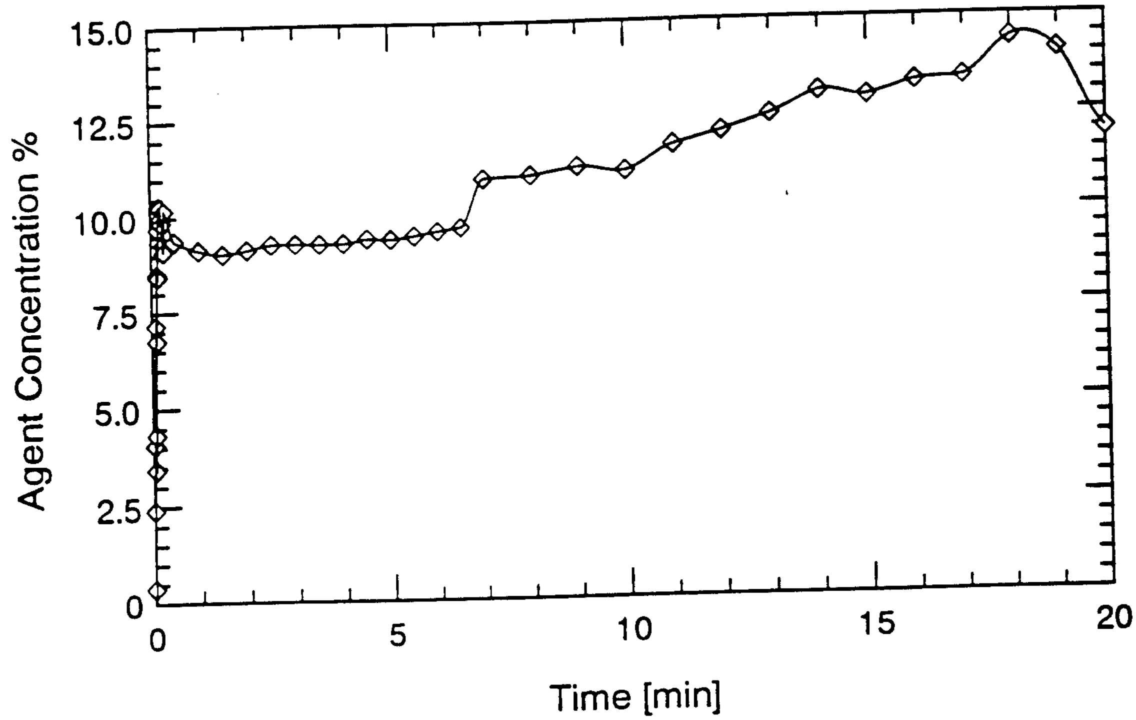



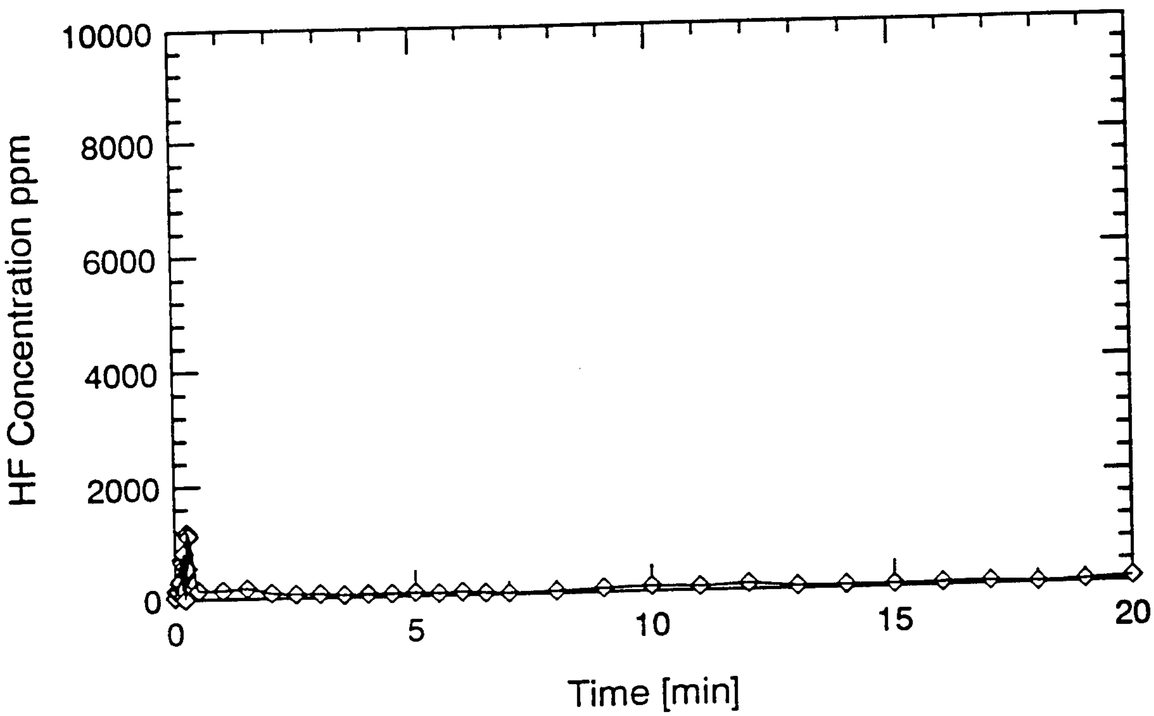

Compartment Temperatures
TEST #10




Oxygen Concentrations
TEST #10




Agent and HF Concentrations
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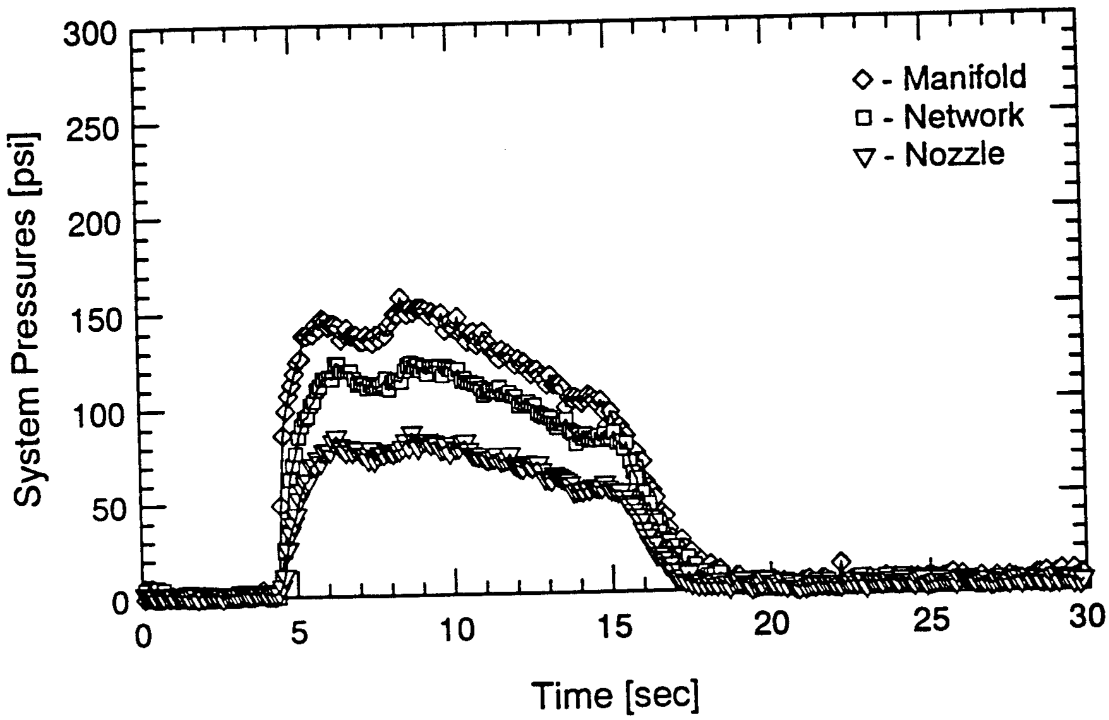
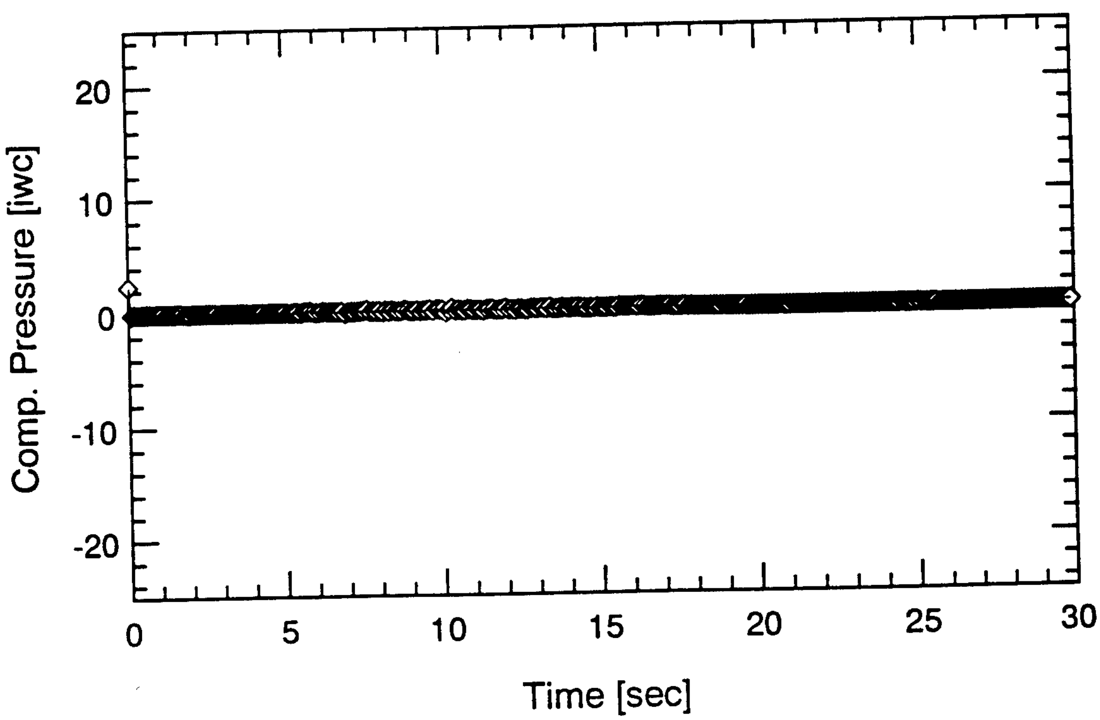
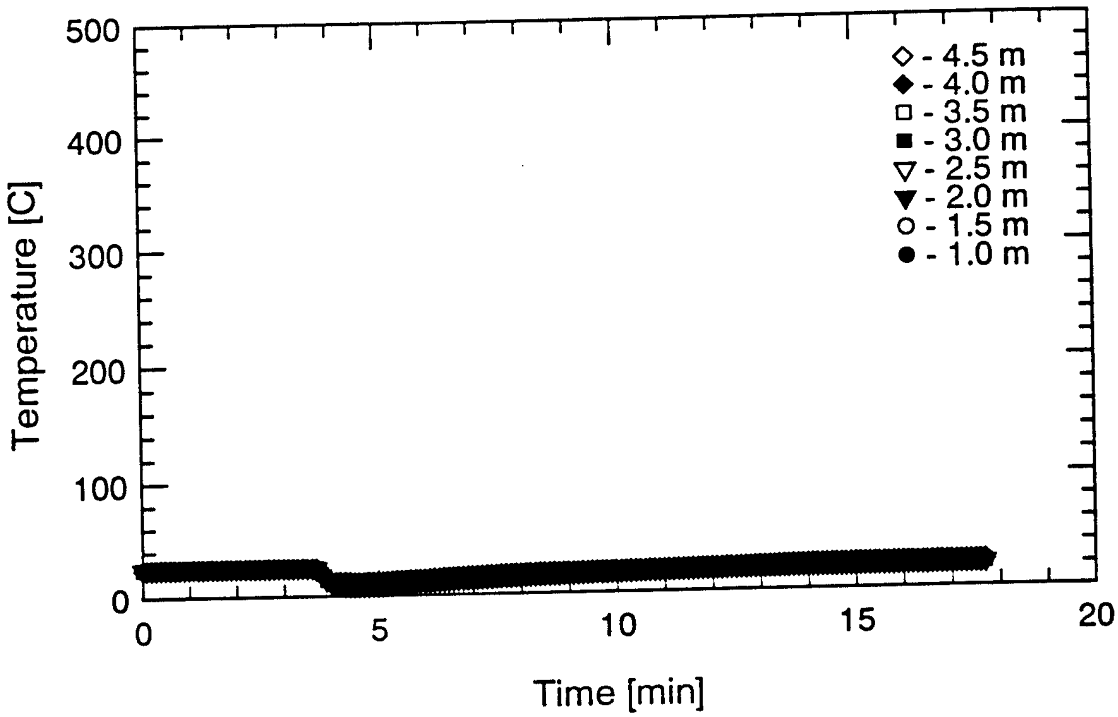
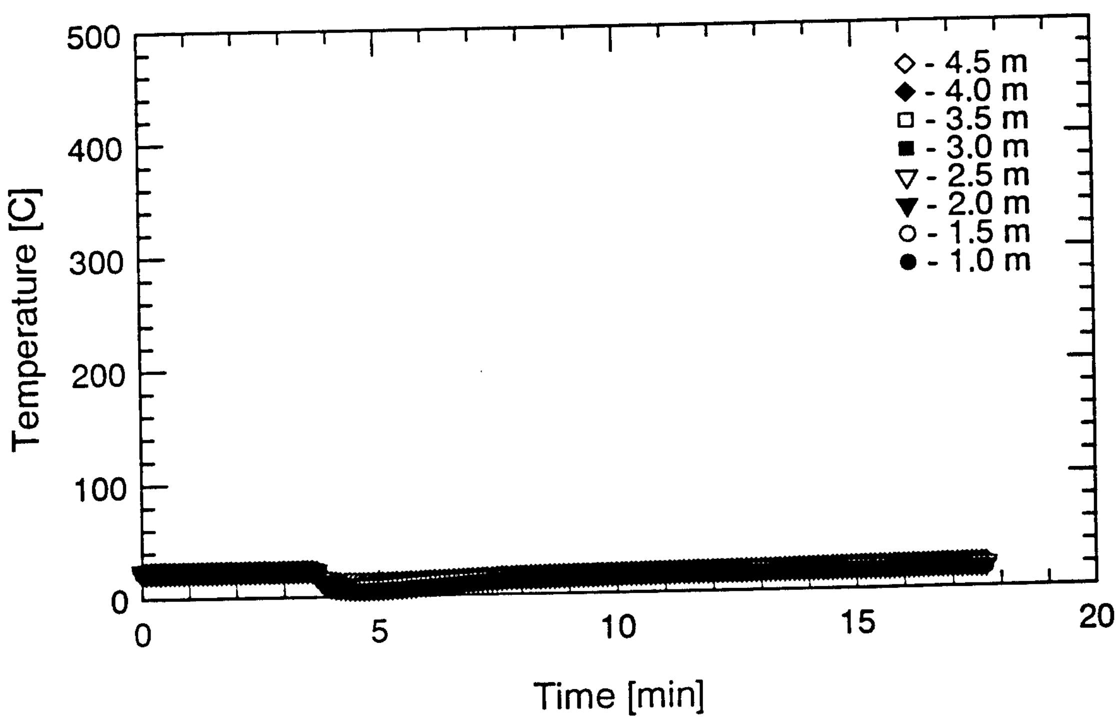



Pressure Measurements
TEST #10




Compartment Temperatures
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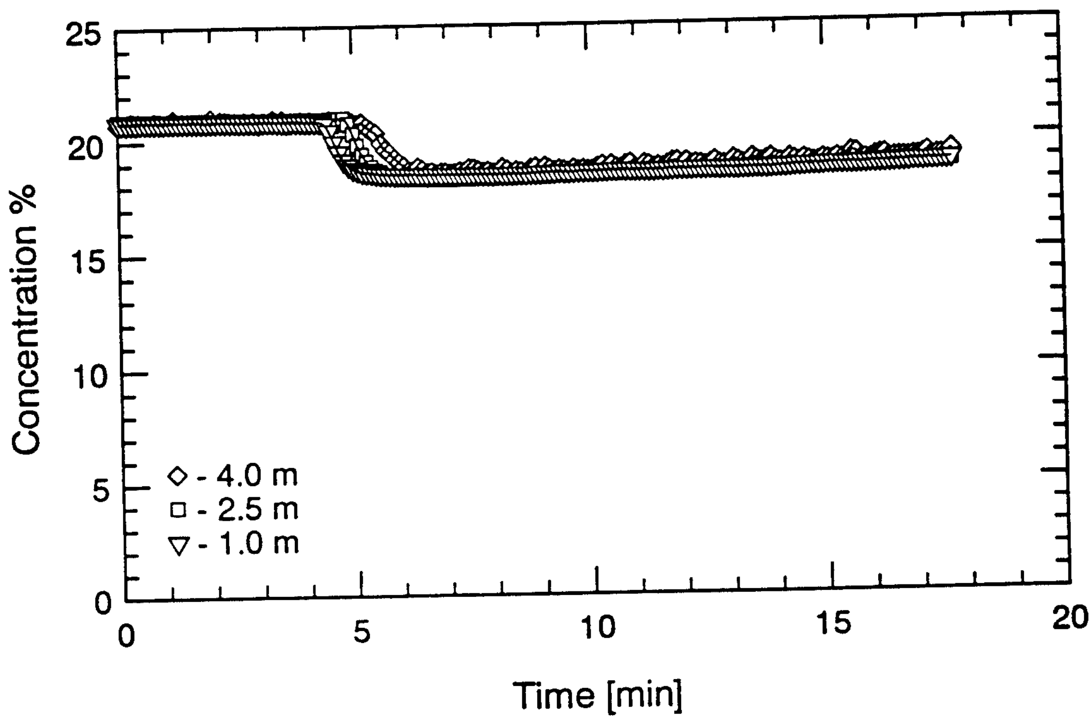
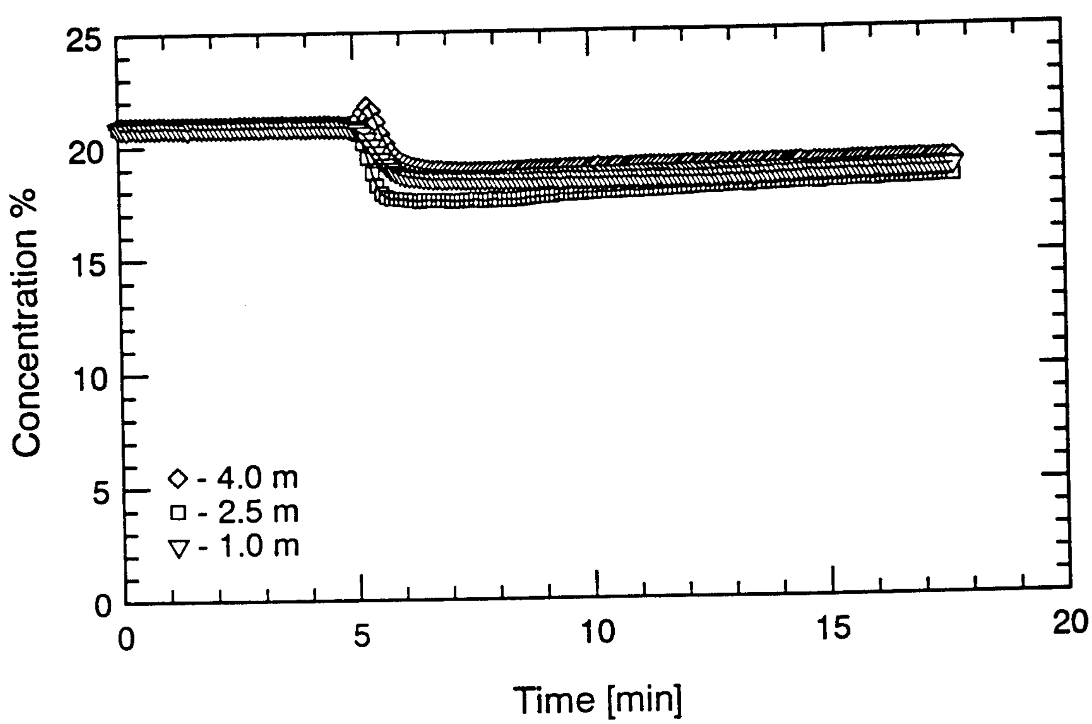
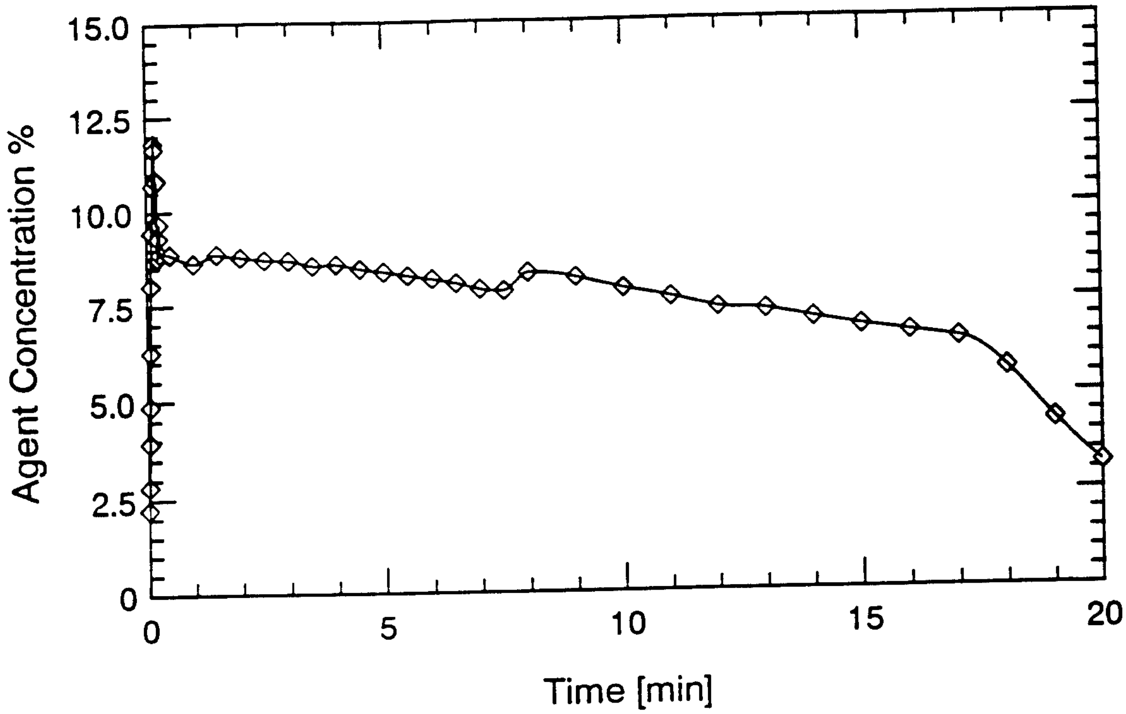
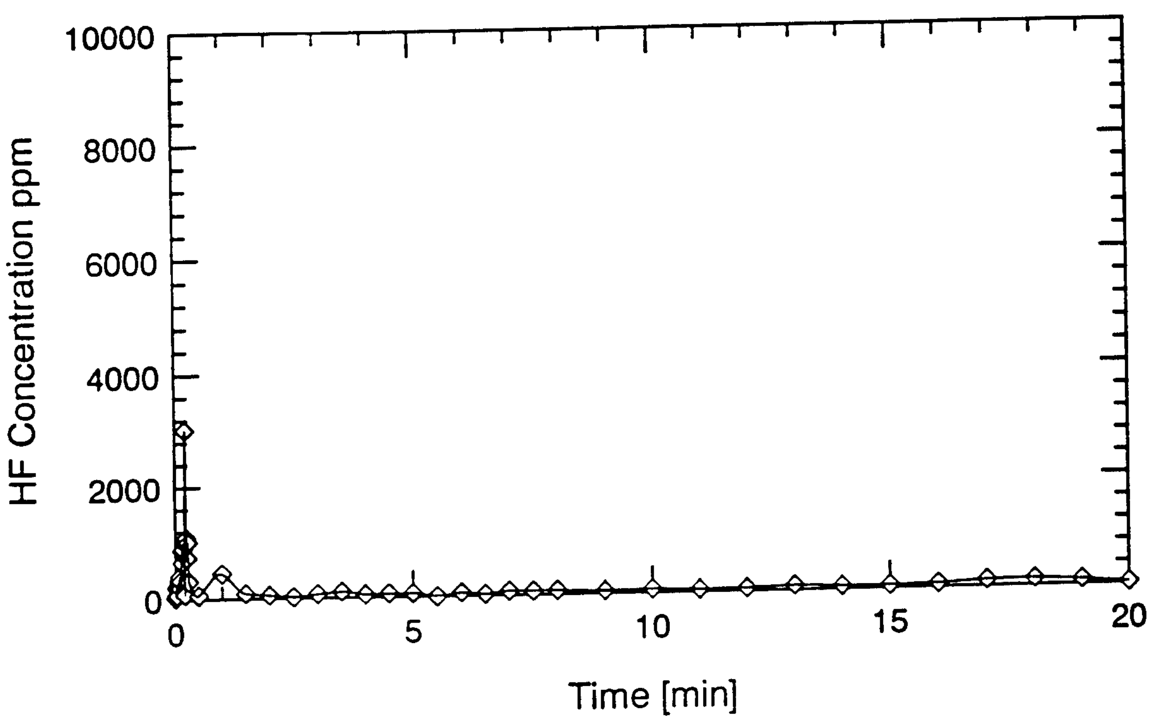


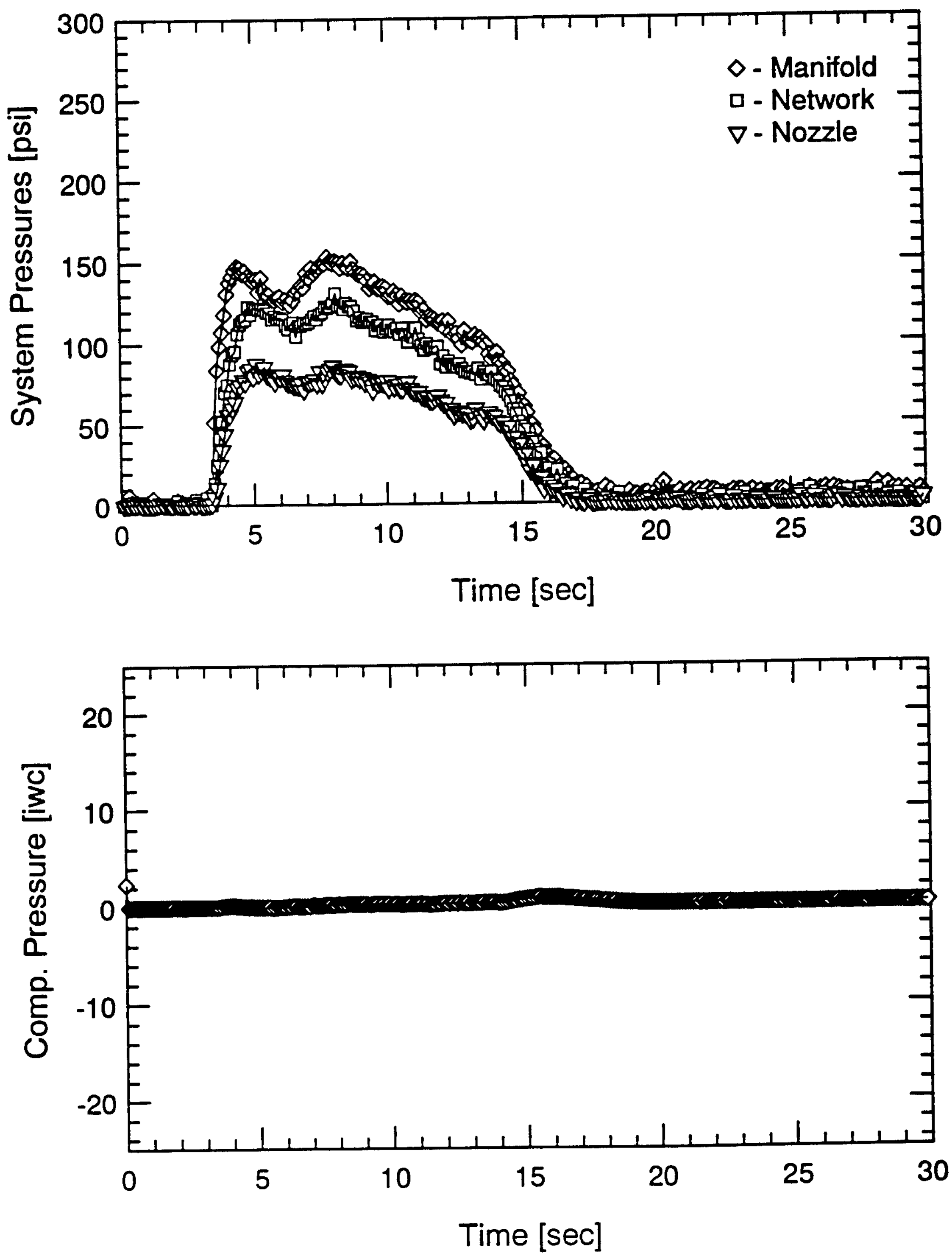




Oxygen Concentrations
TEST #11

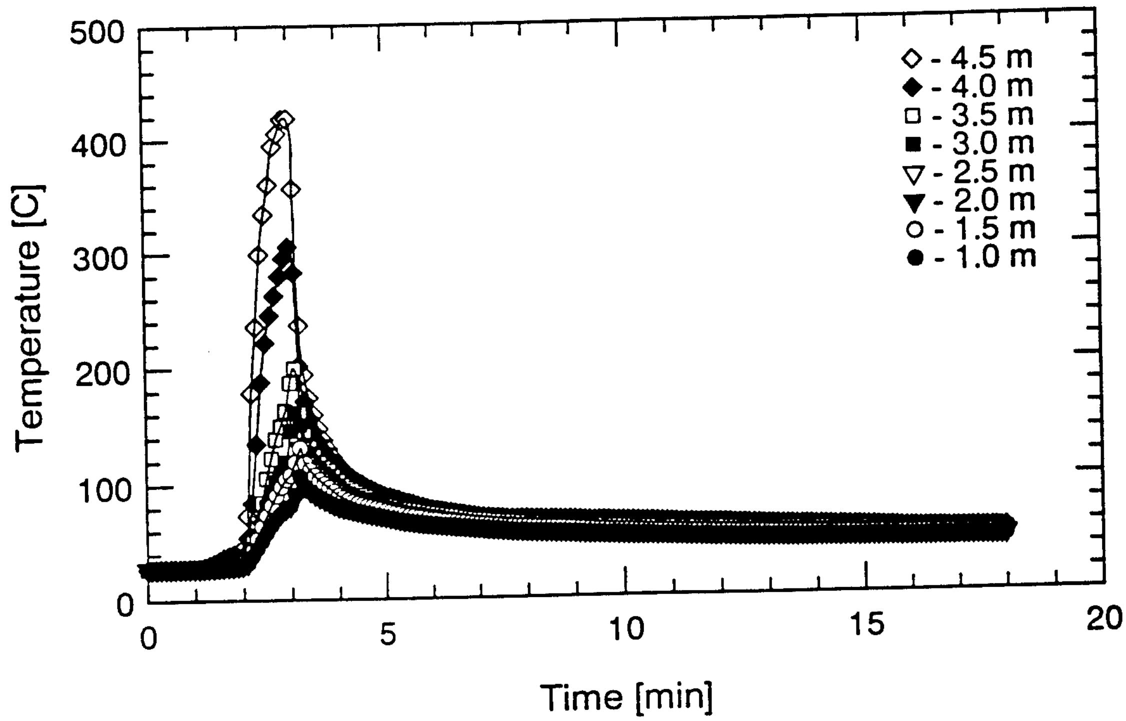


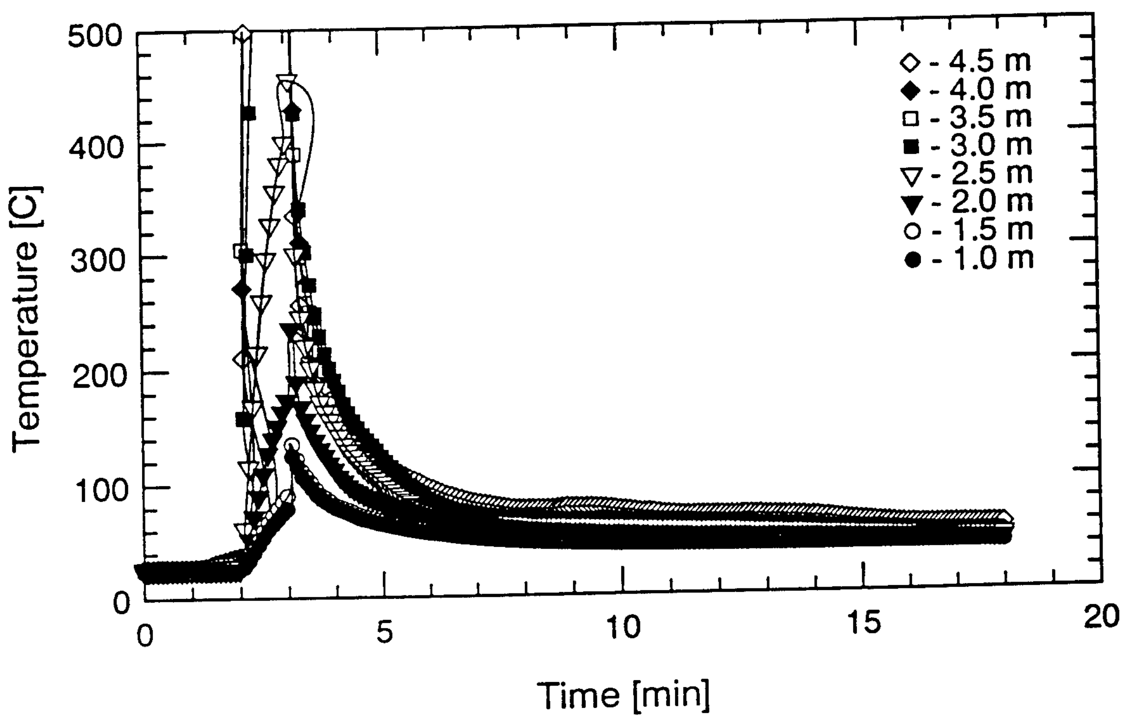




Agent and HF Concentrations
TEST #11

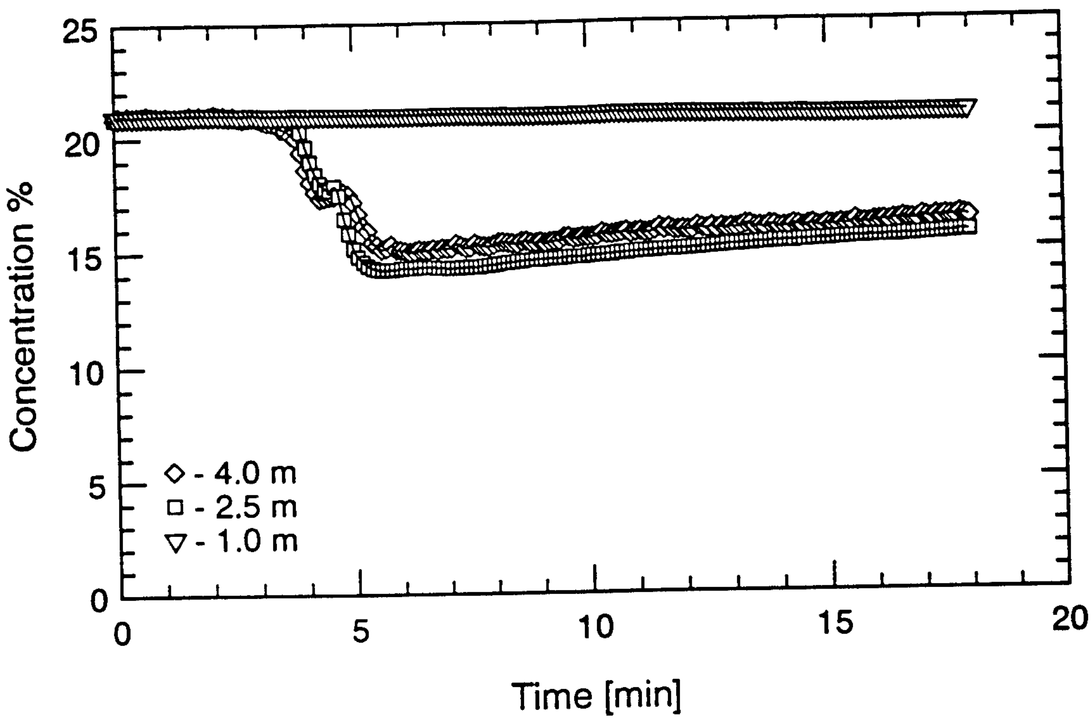


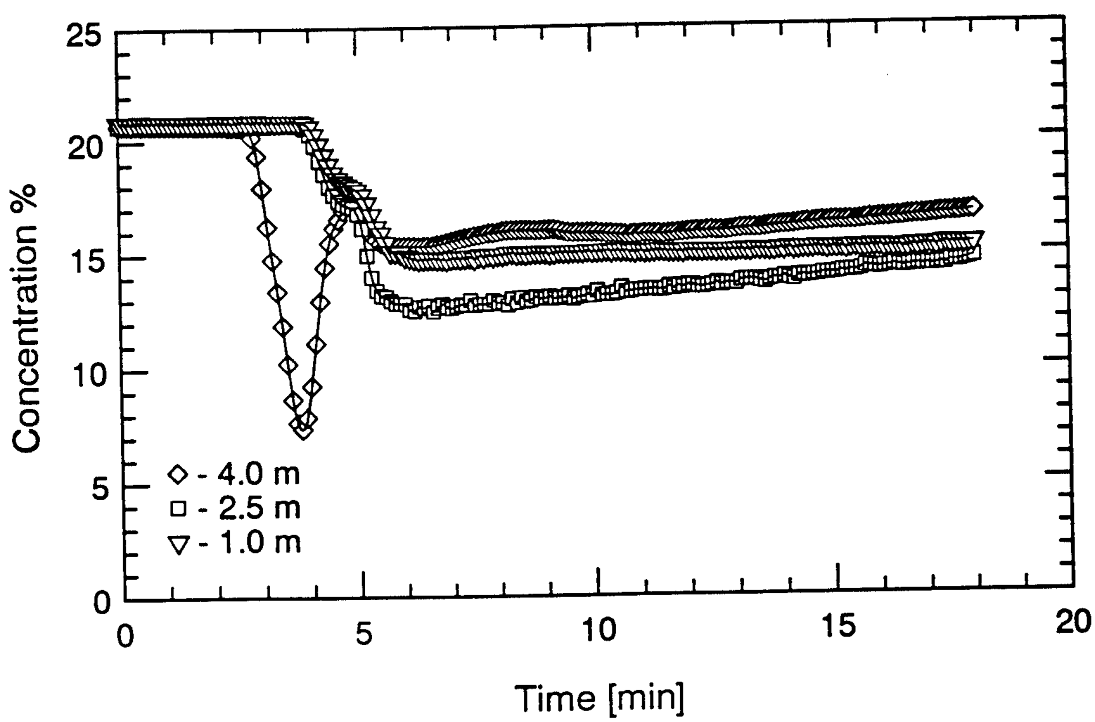

Pressure Measurements
TEST #11



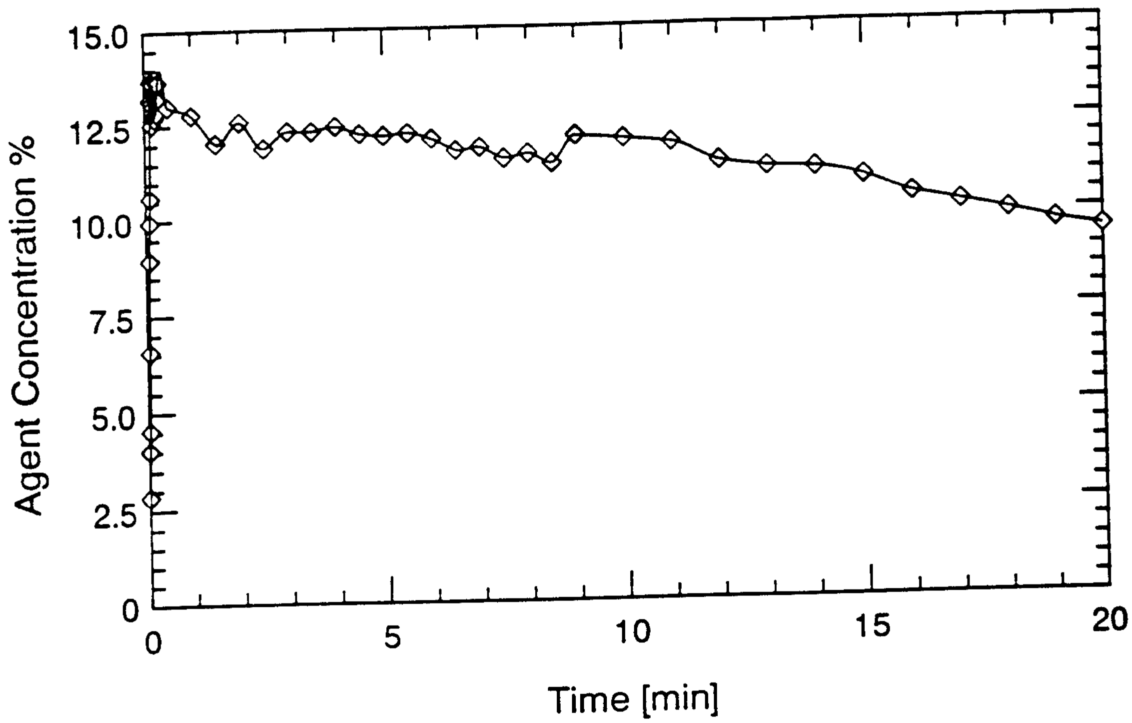



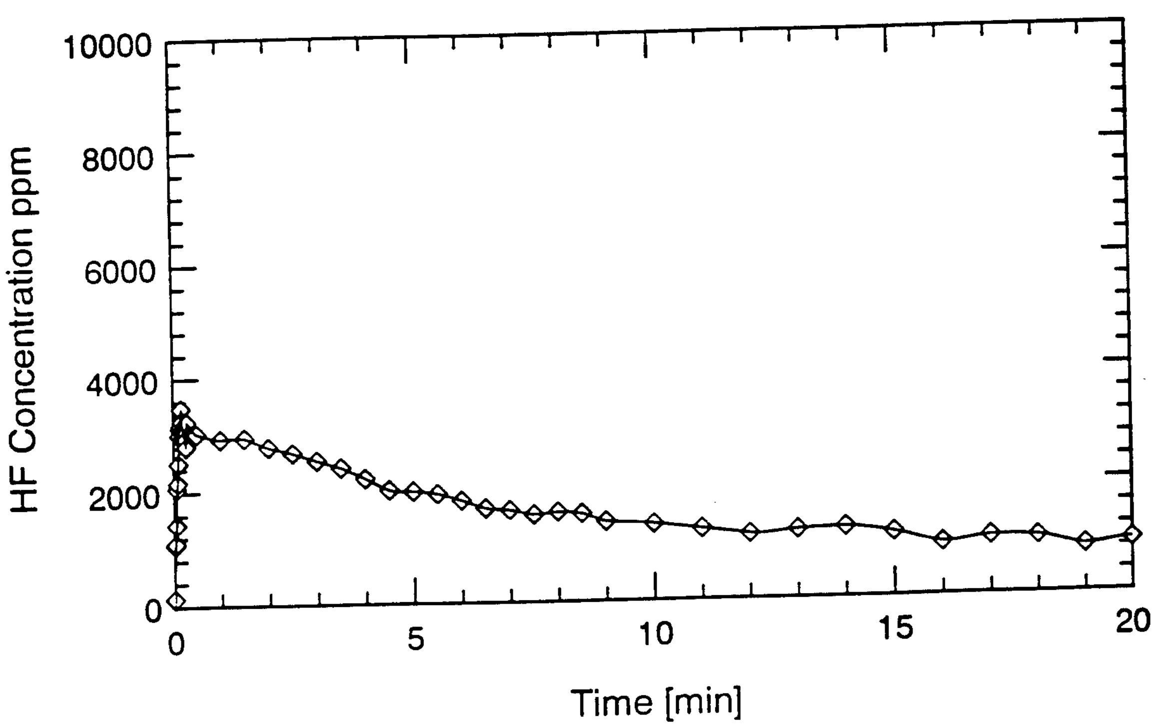

Compartment Temperatures
TEST #12



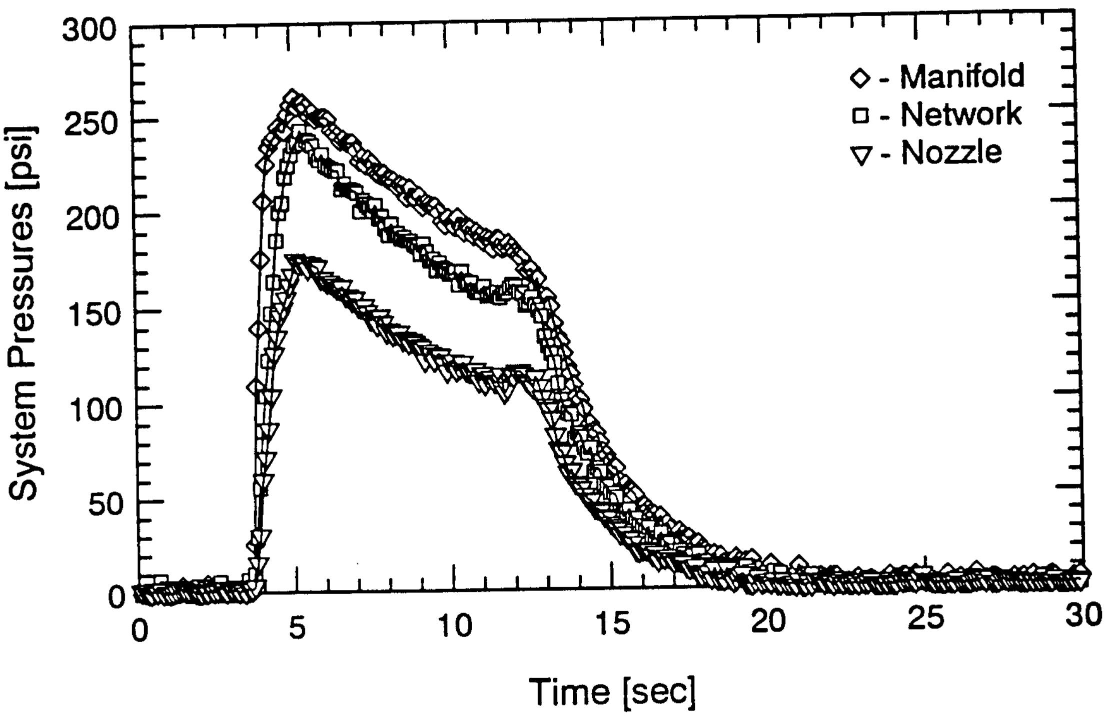



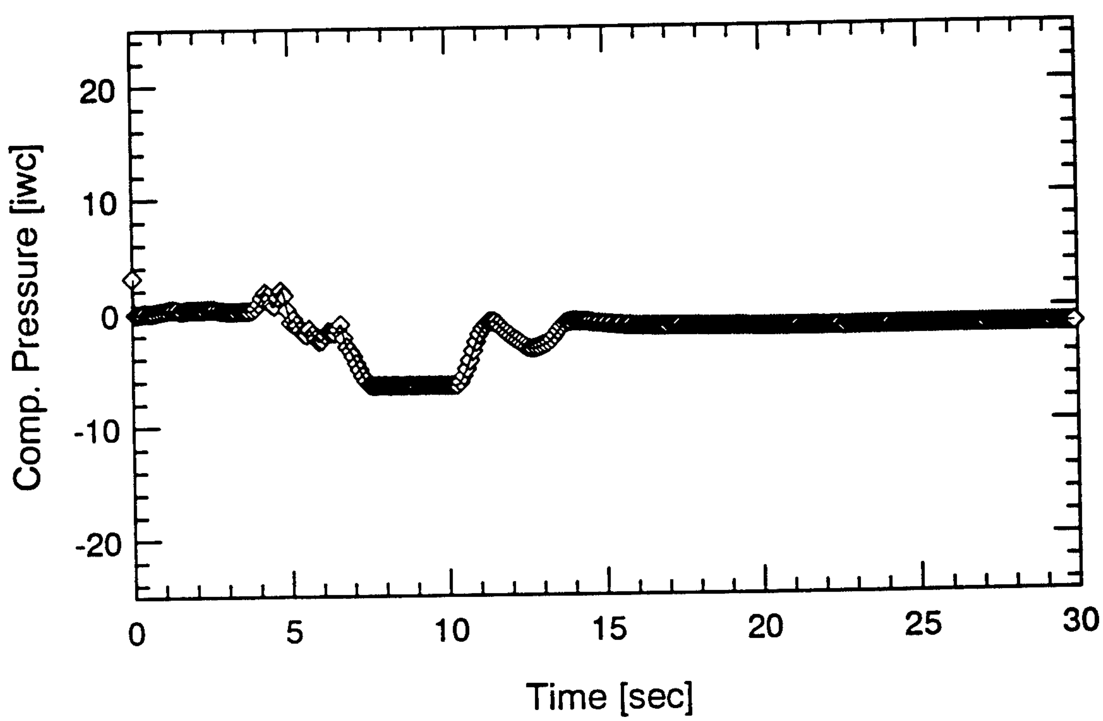

Oxygen Concentrations
TEST #12



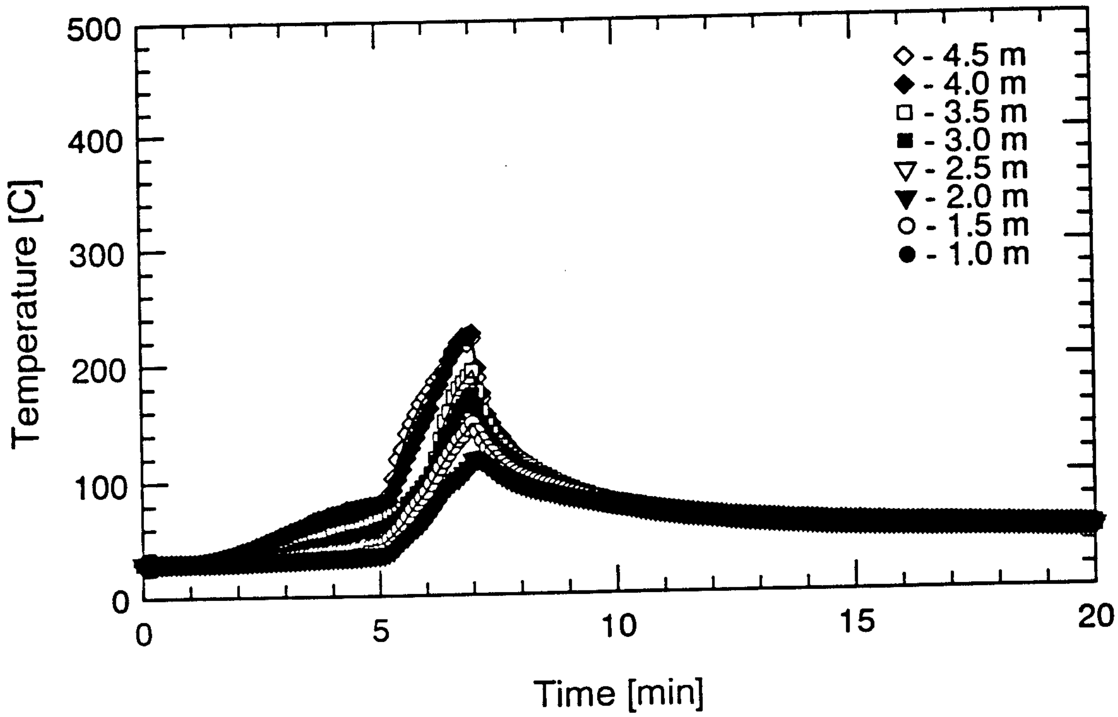



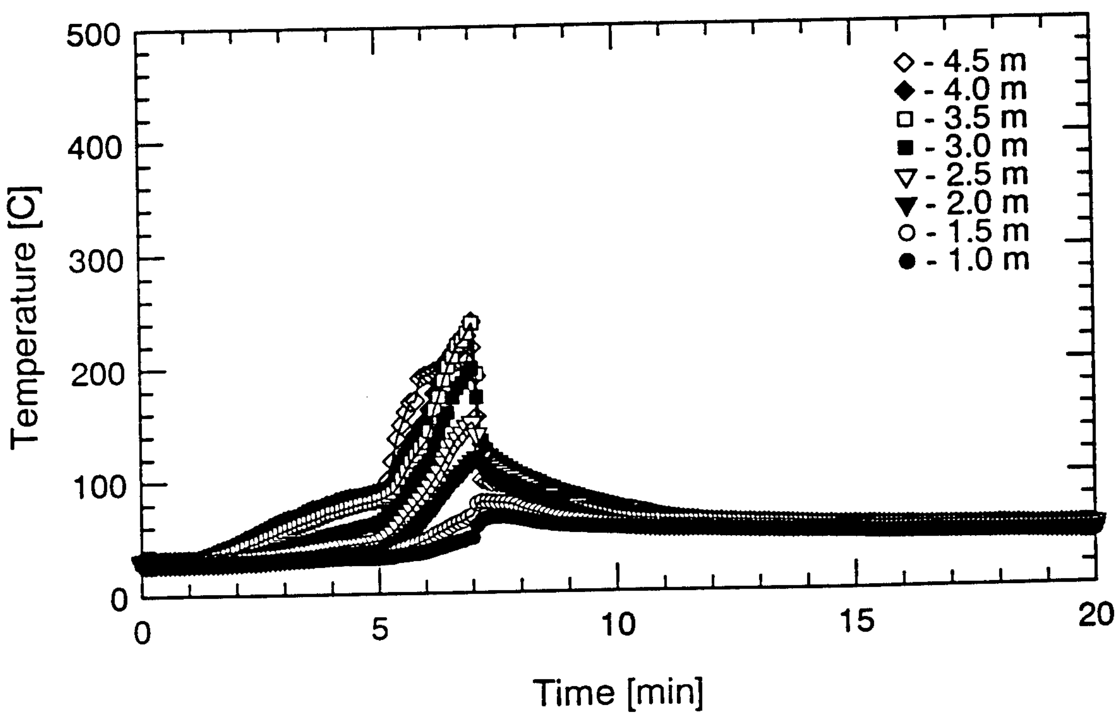

Agent and HF Concentrations
TEST #12



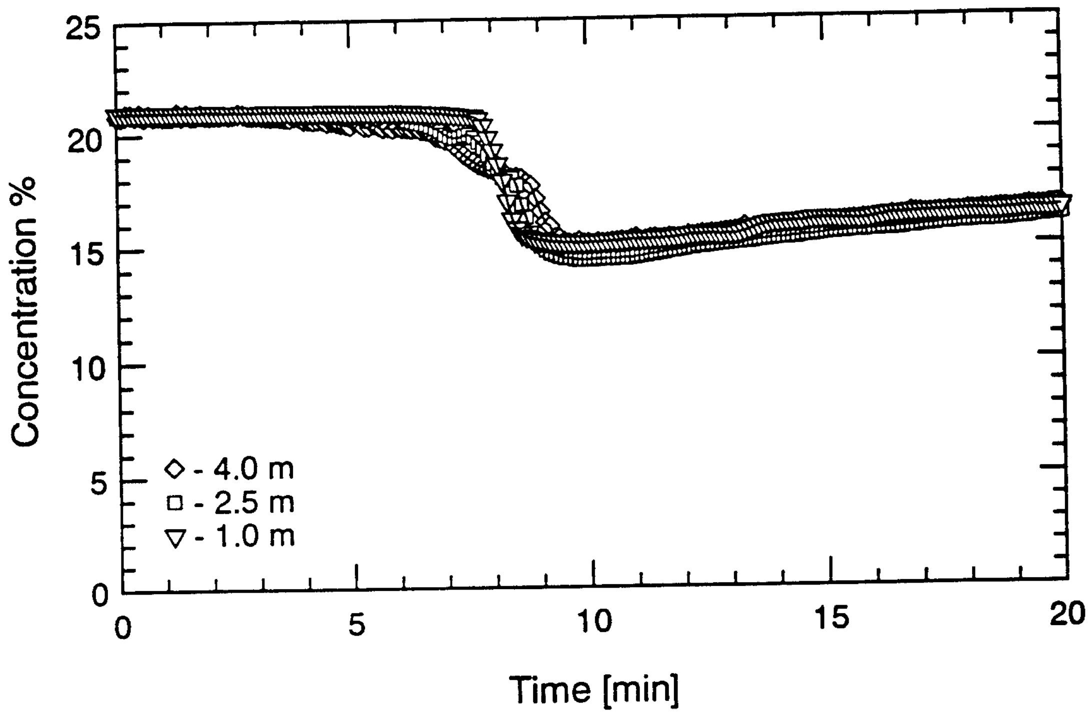



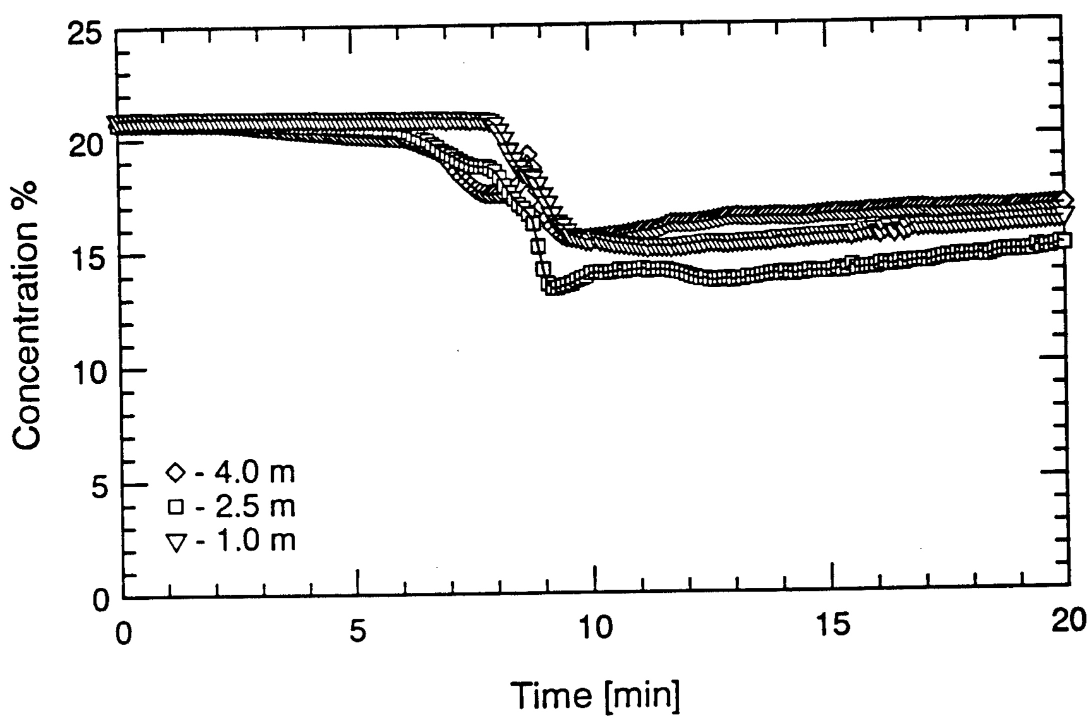

Pressure Measurements
TEST #12



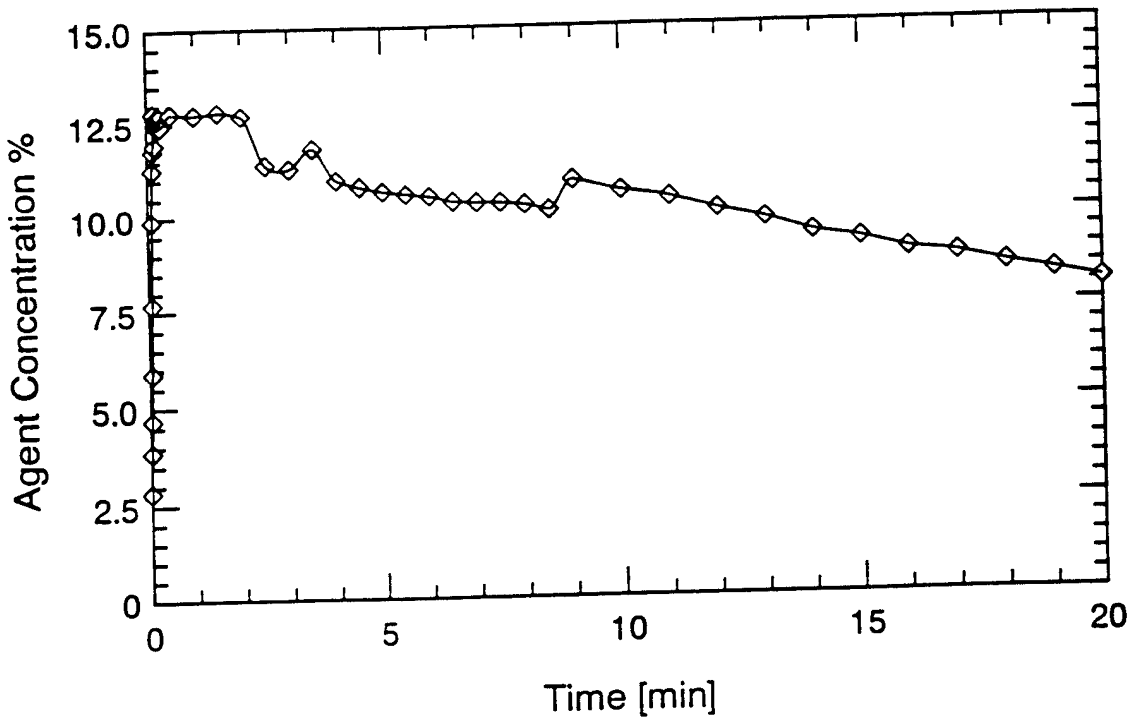



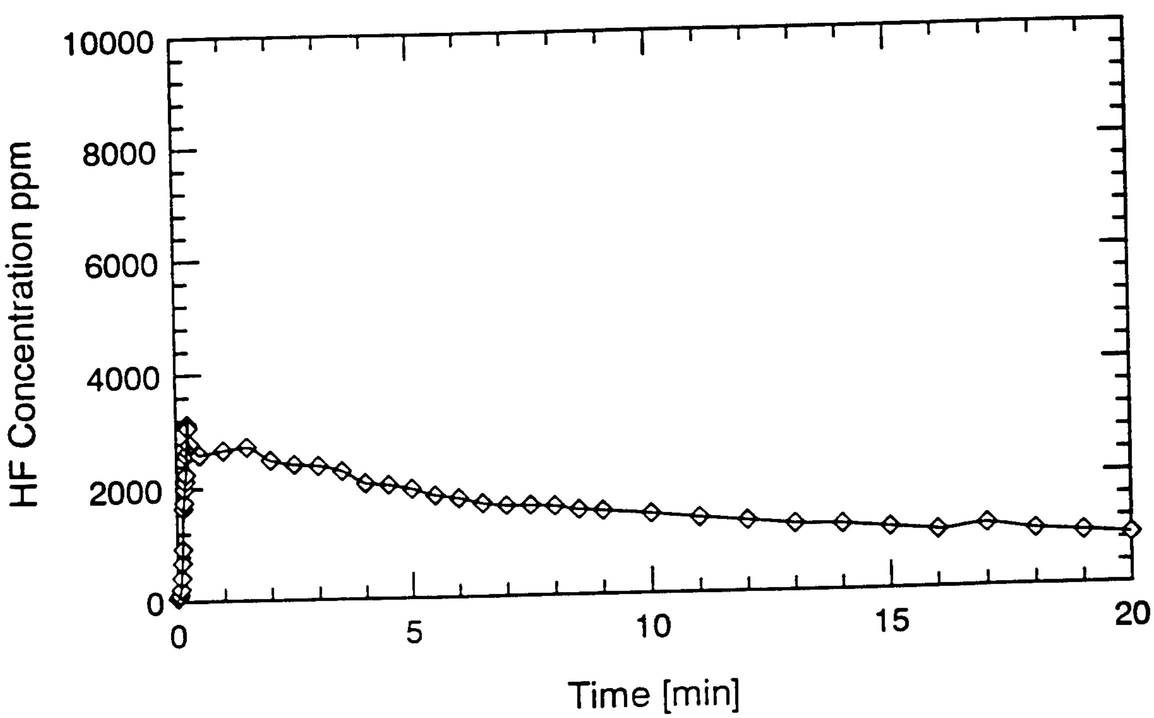

Compartment Temperatures
TEST #13



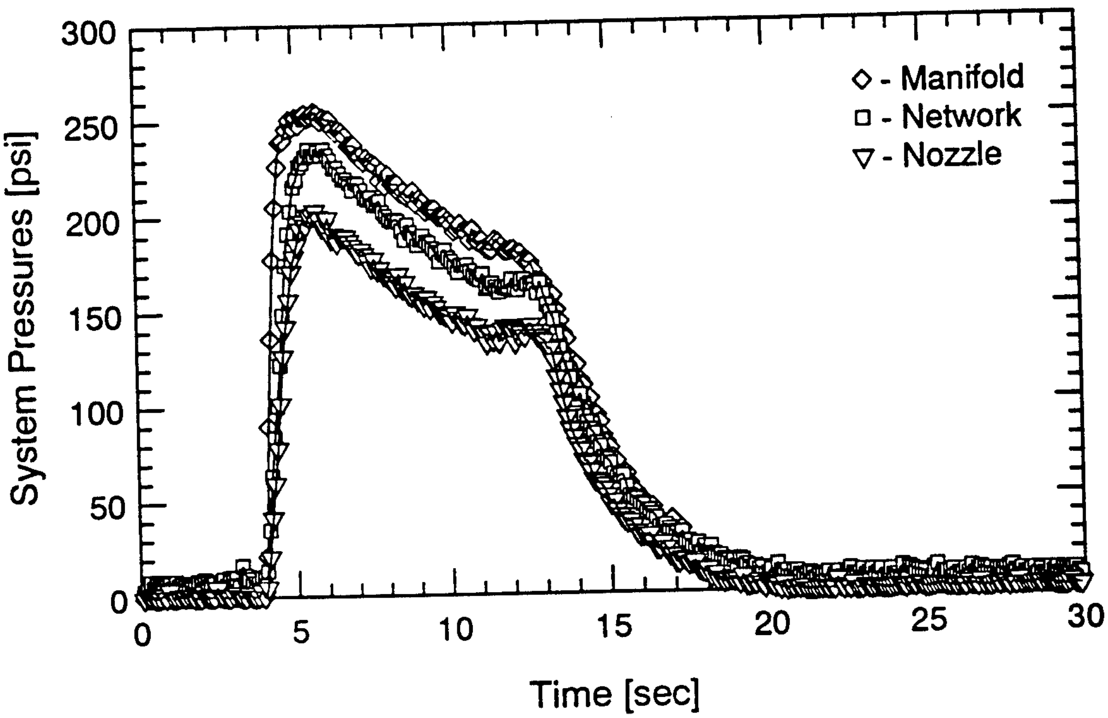



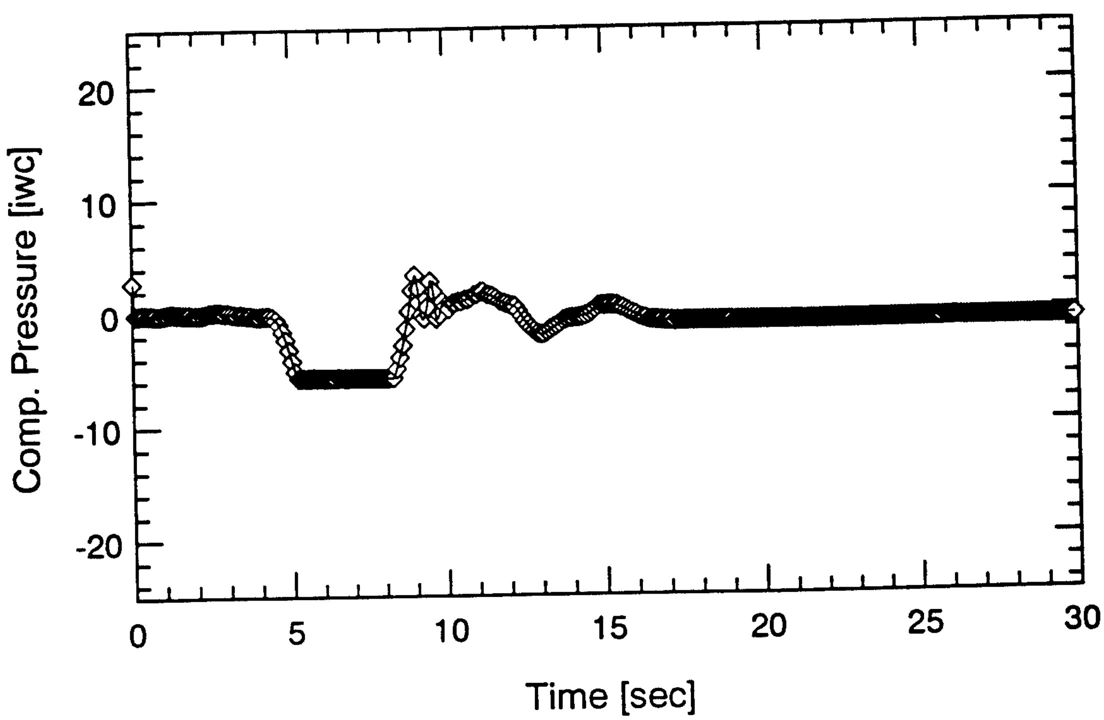

Oxygen Concentrations
TEST #13



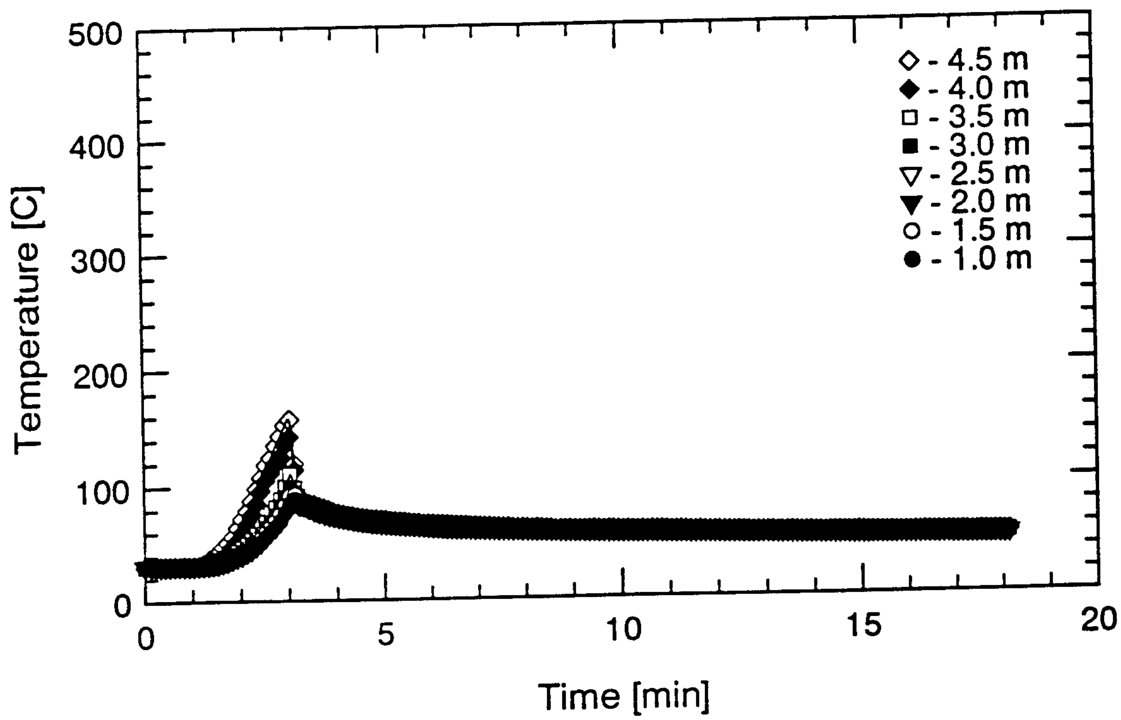



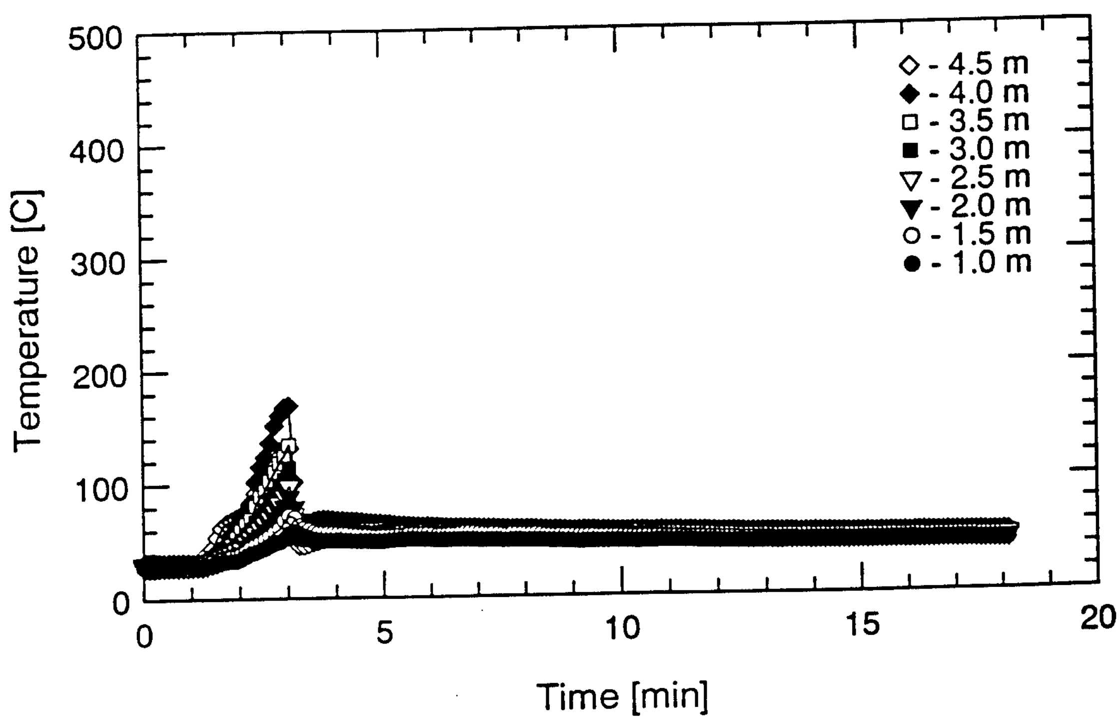

Agent and HF Concentrations
TEST #13



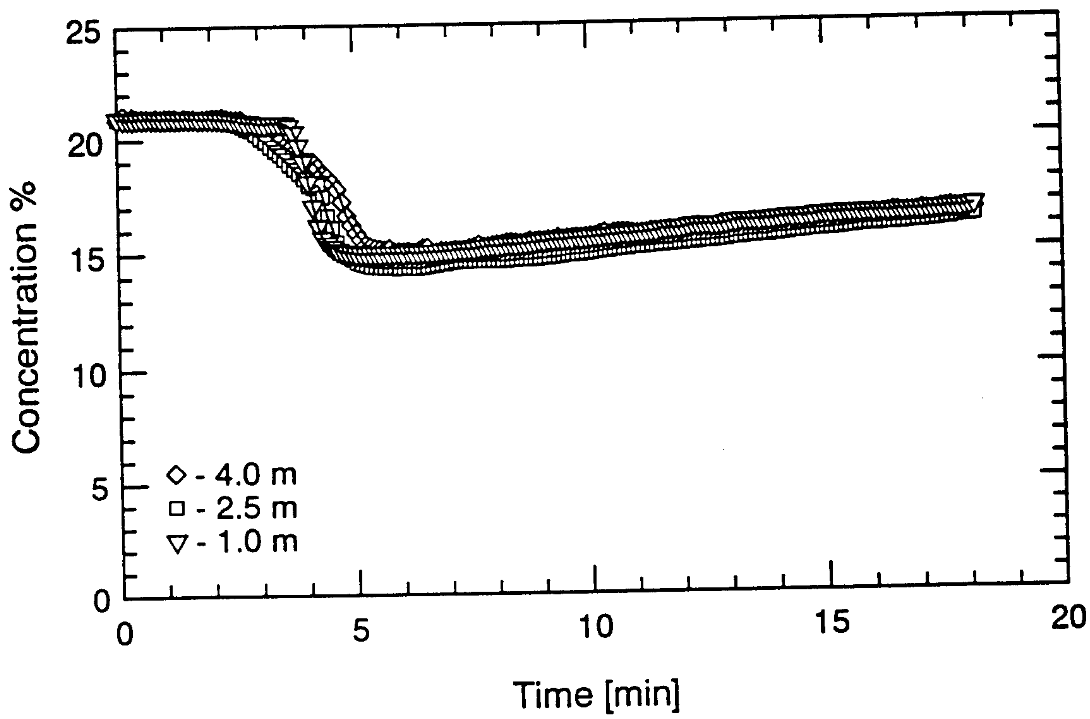



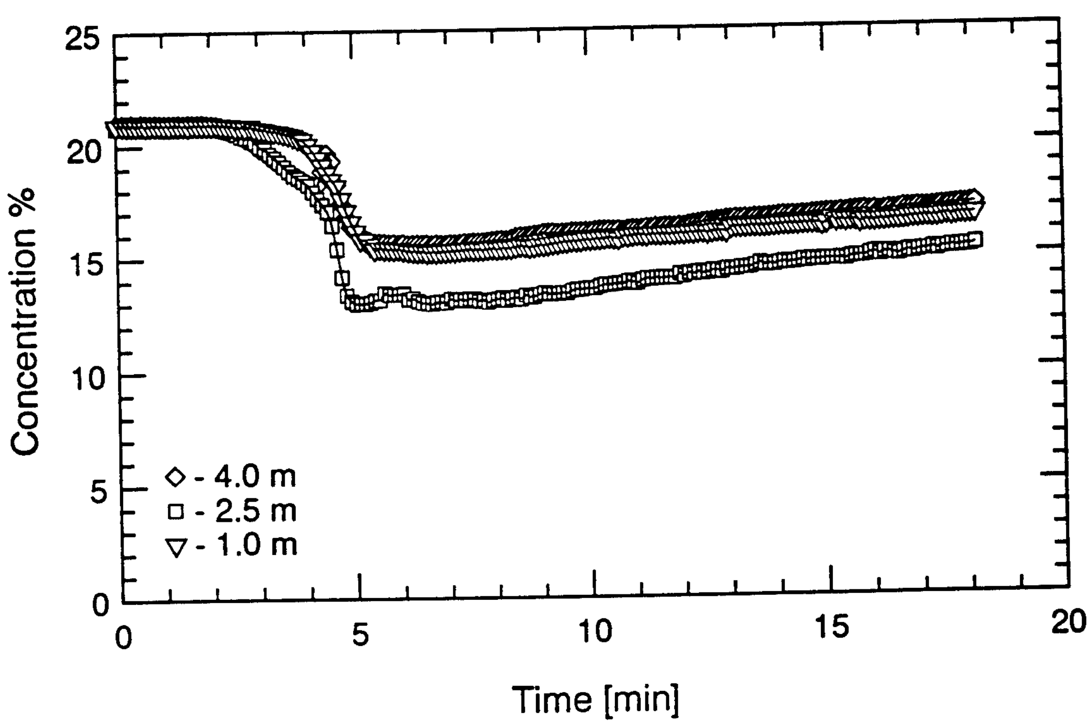

Pressure Measurements
TEST #13



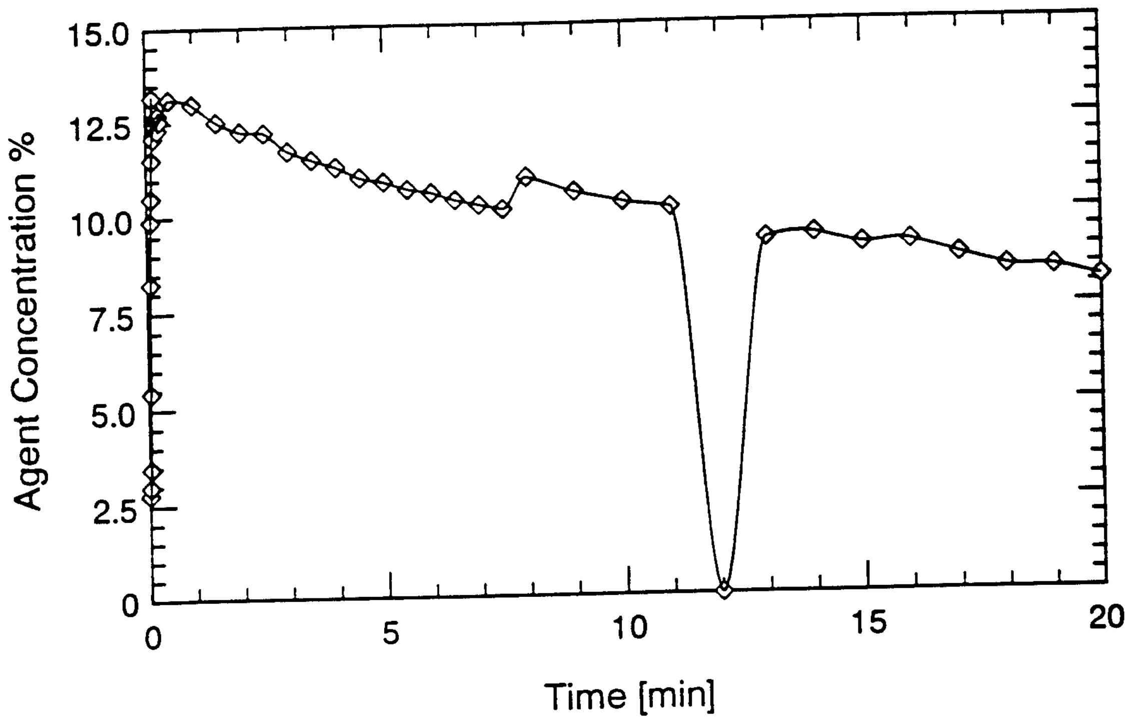



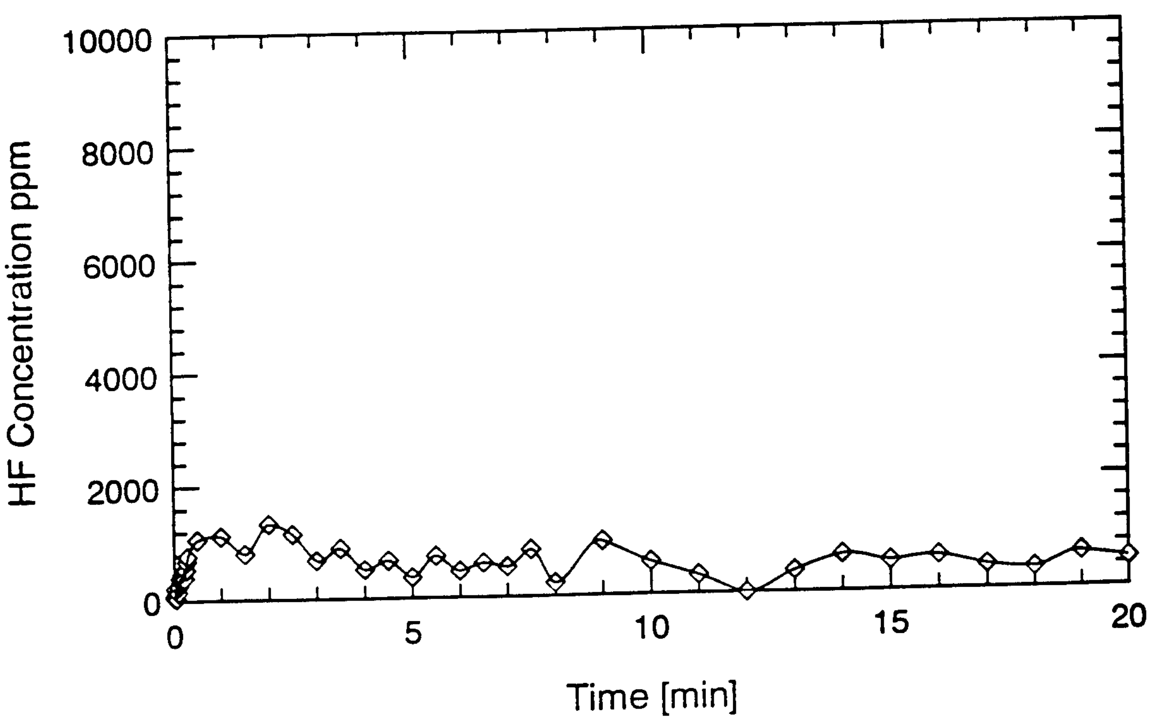

Compartment Temperatures
TEST #14



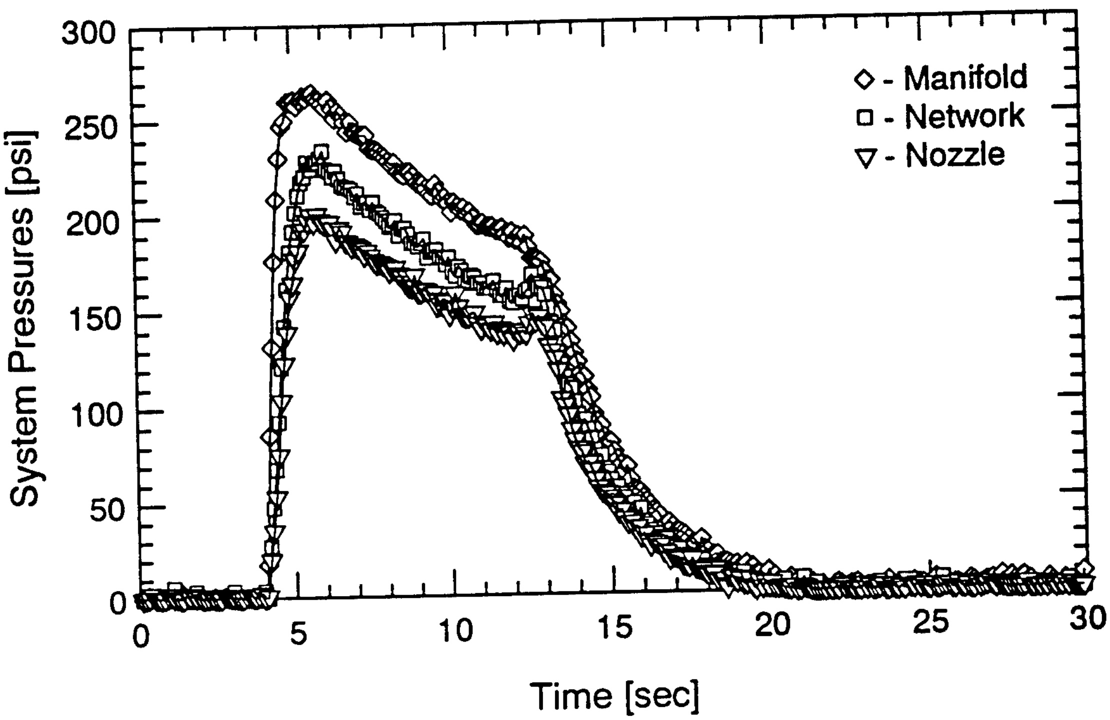



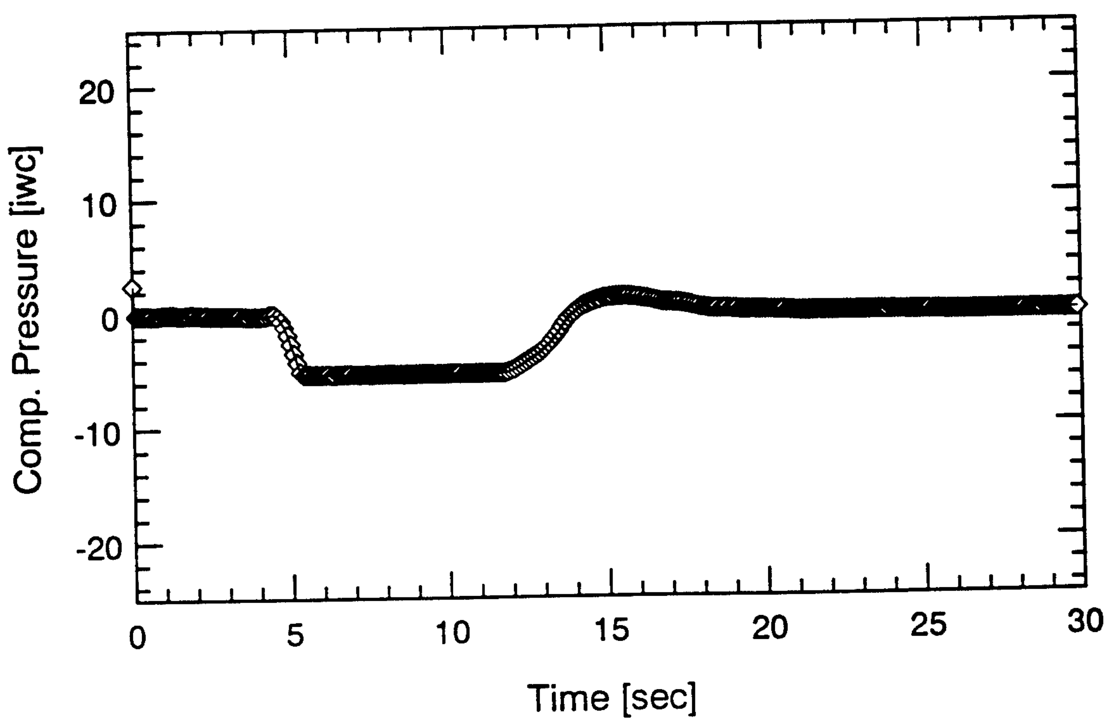

Oxygen Concentrations
TEST #14



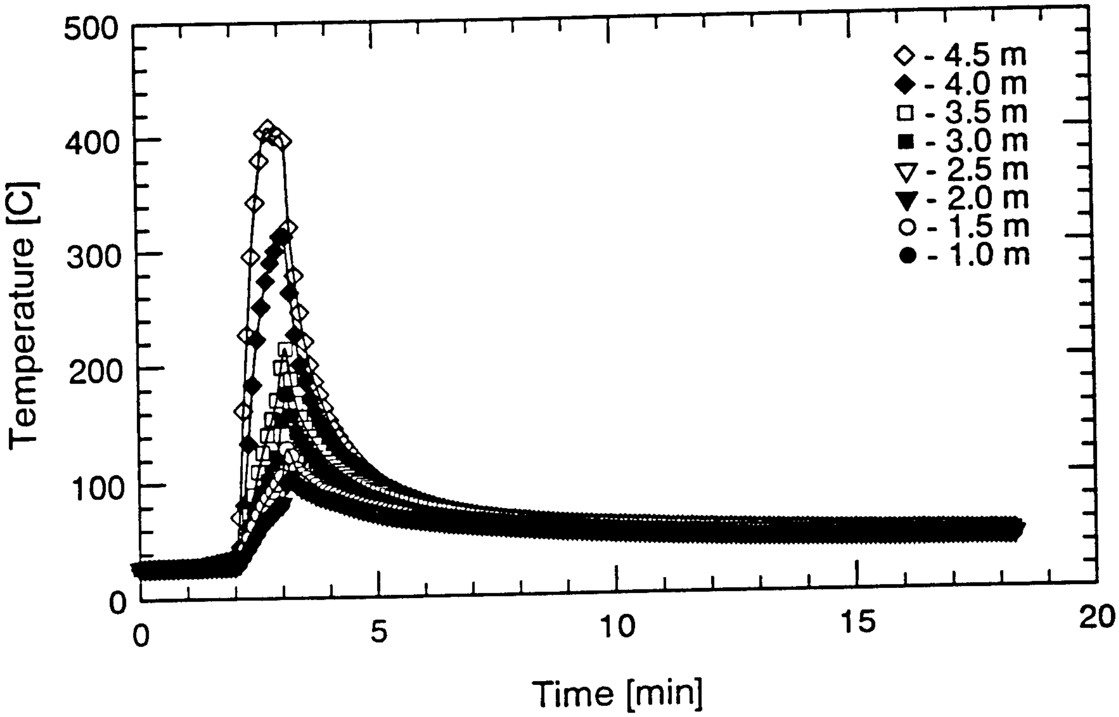



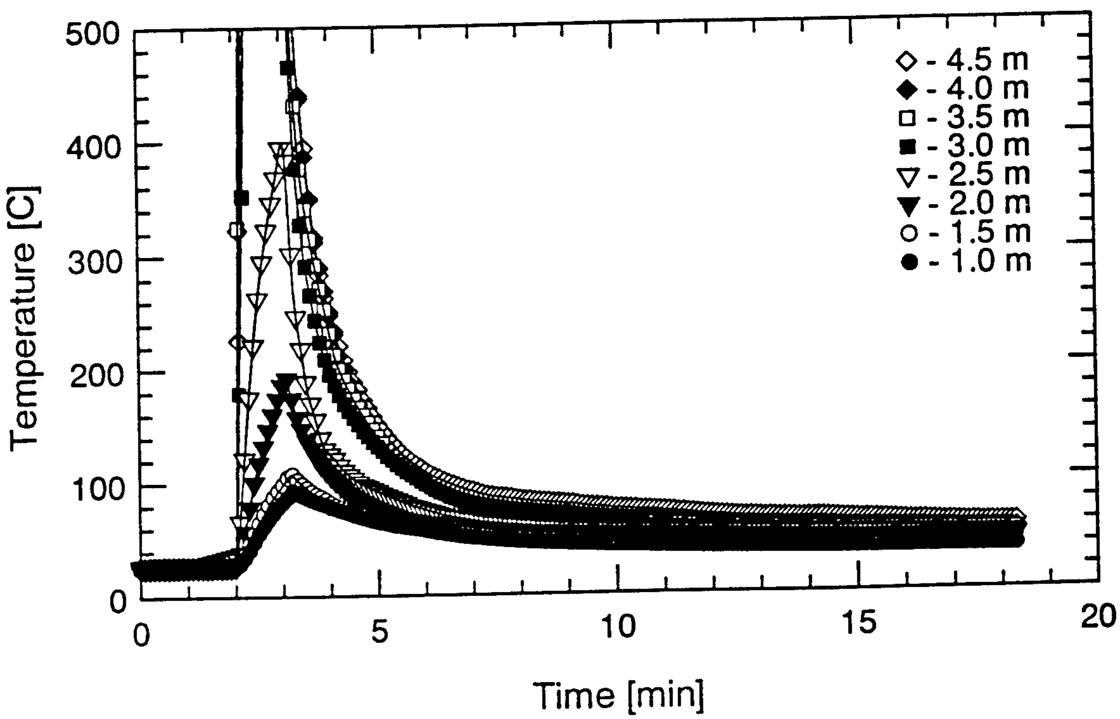

Agent and HF Concentrations
TEST #14



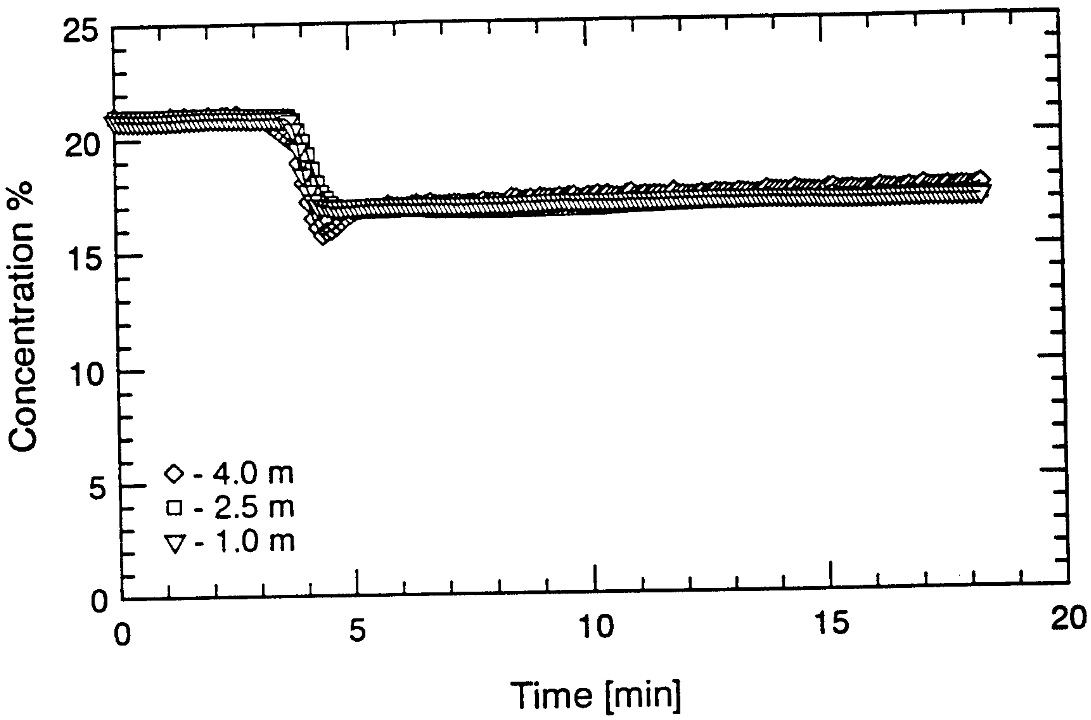



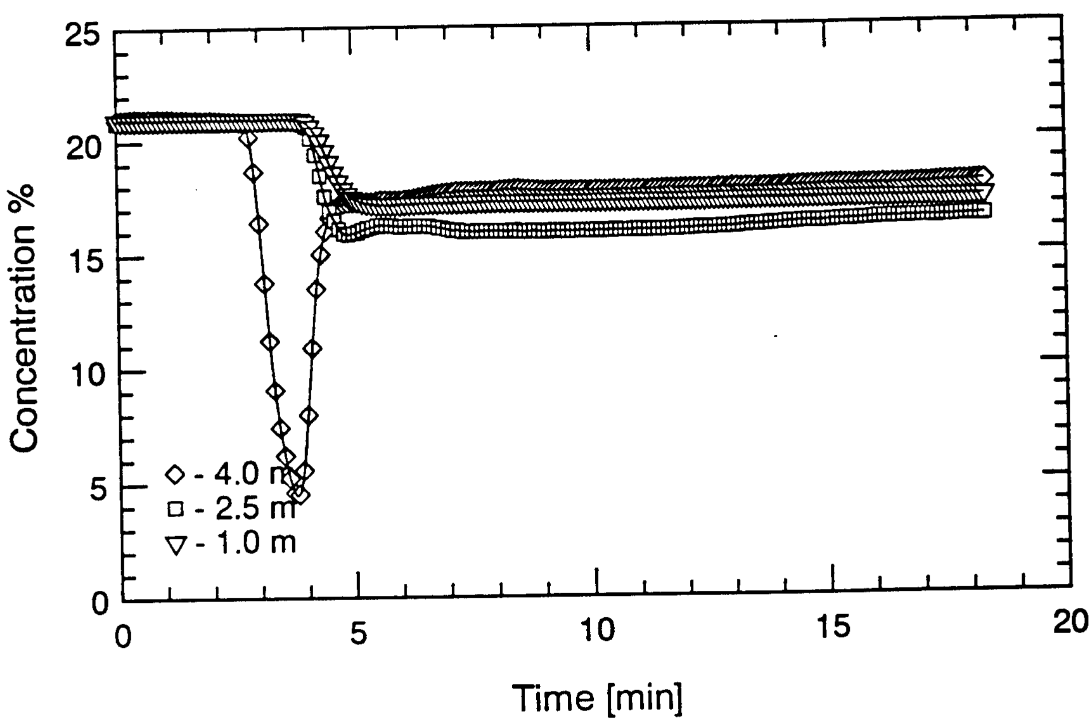

Pressure Measurements
TEST #14



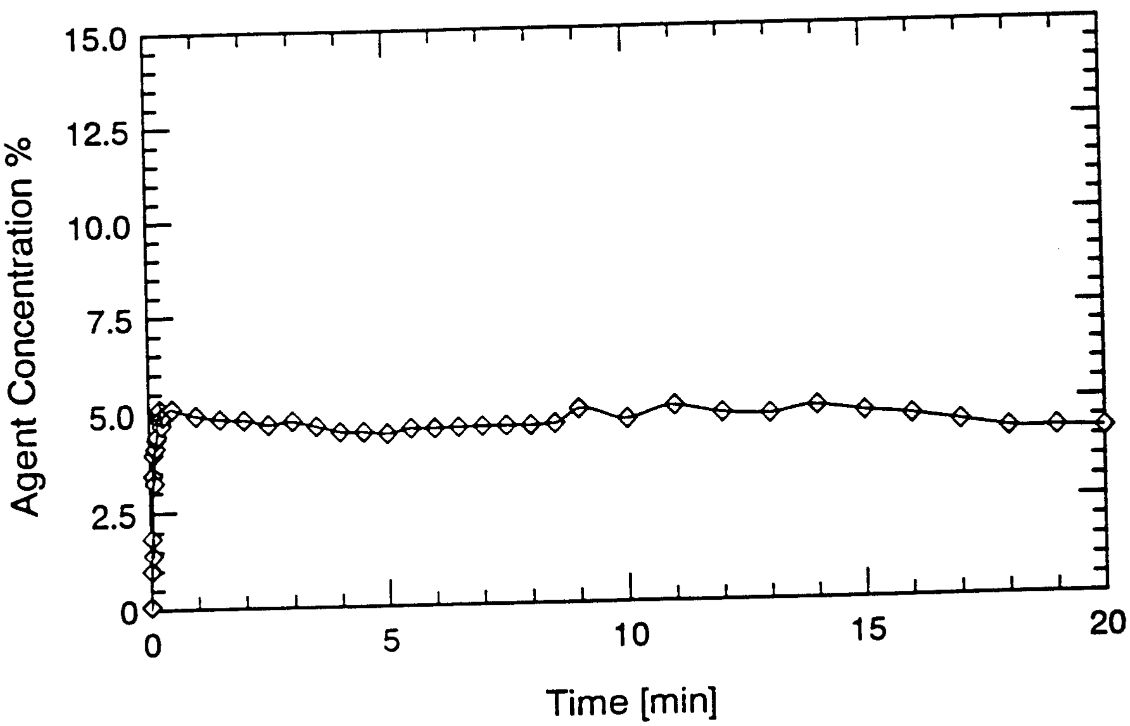



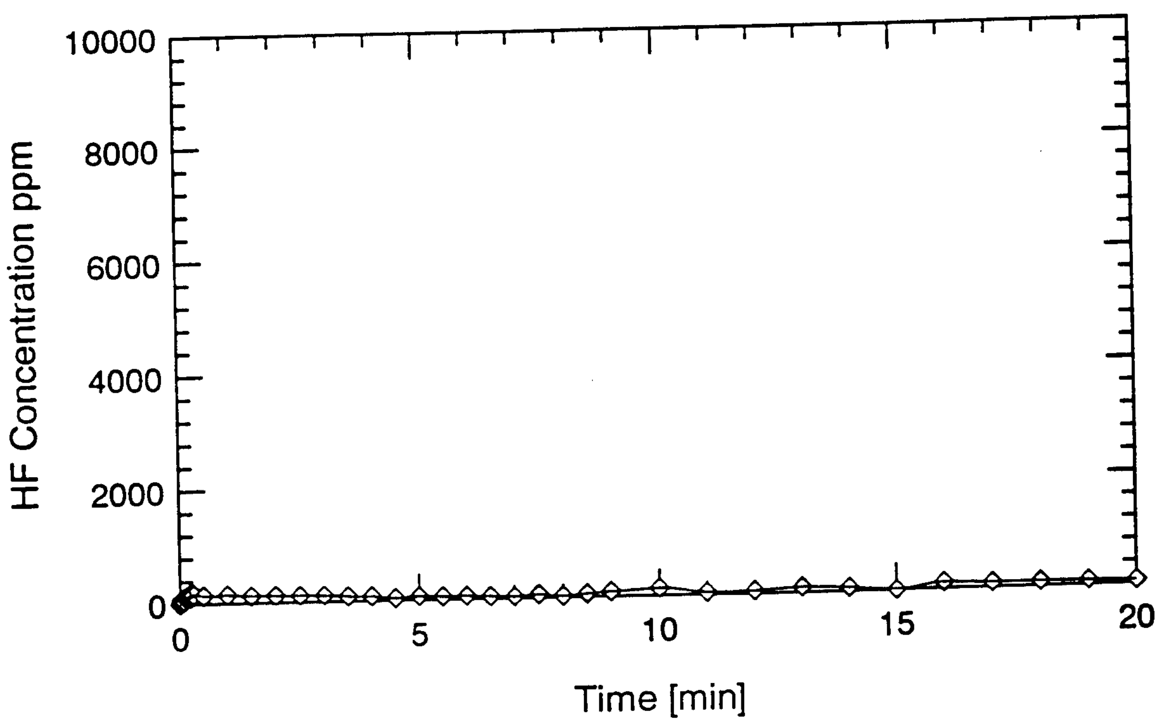

Compartment Temperatures
TEST #15



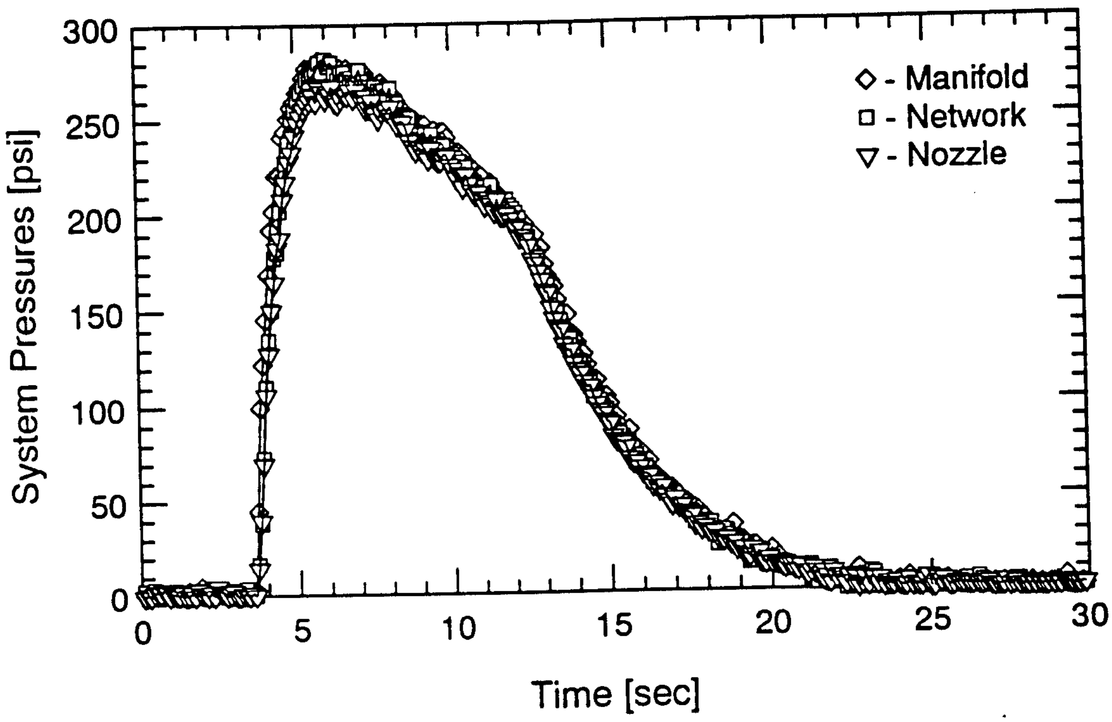



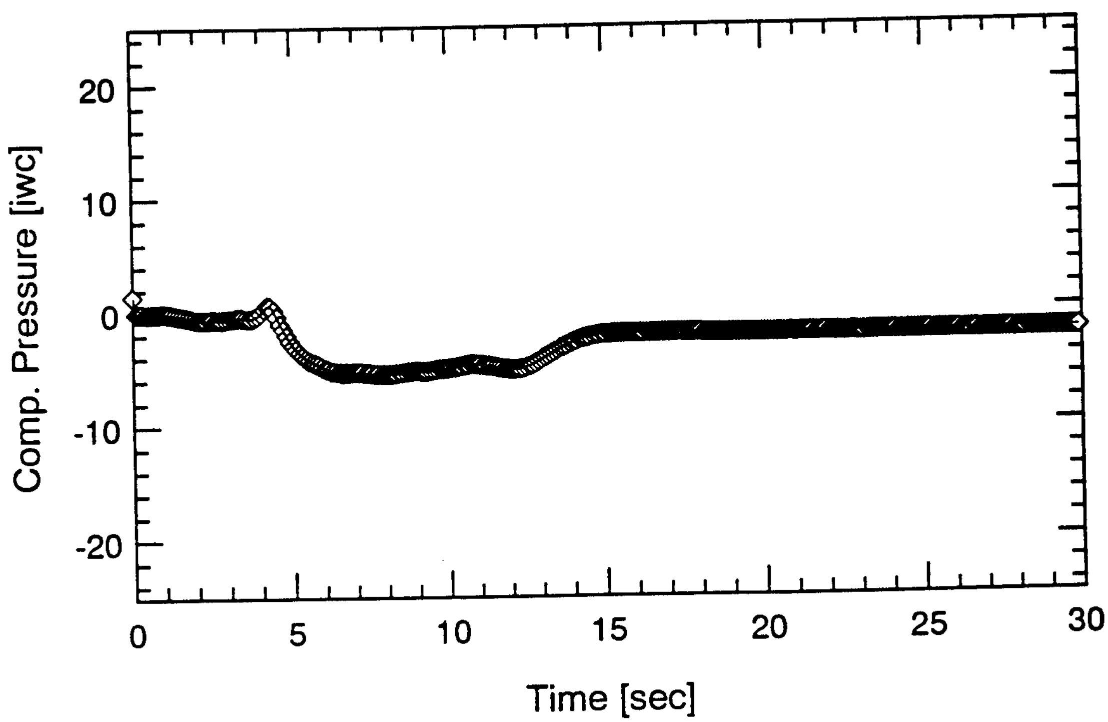

Oxygen Concentrations
TEST #15



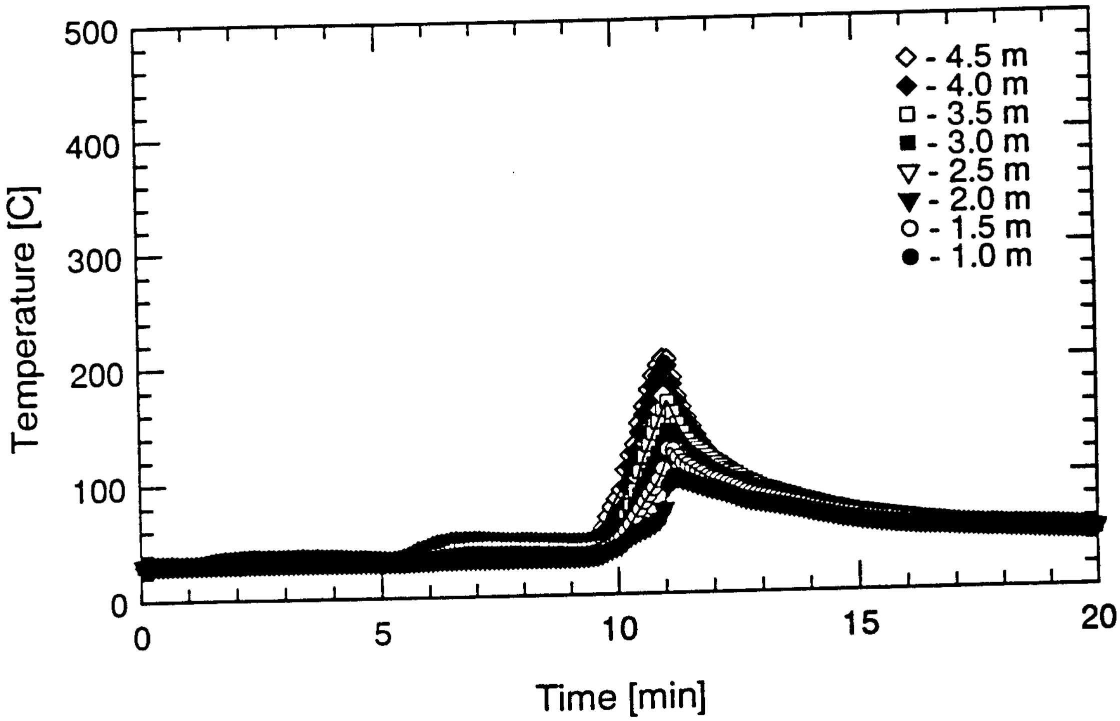



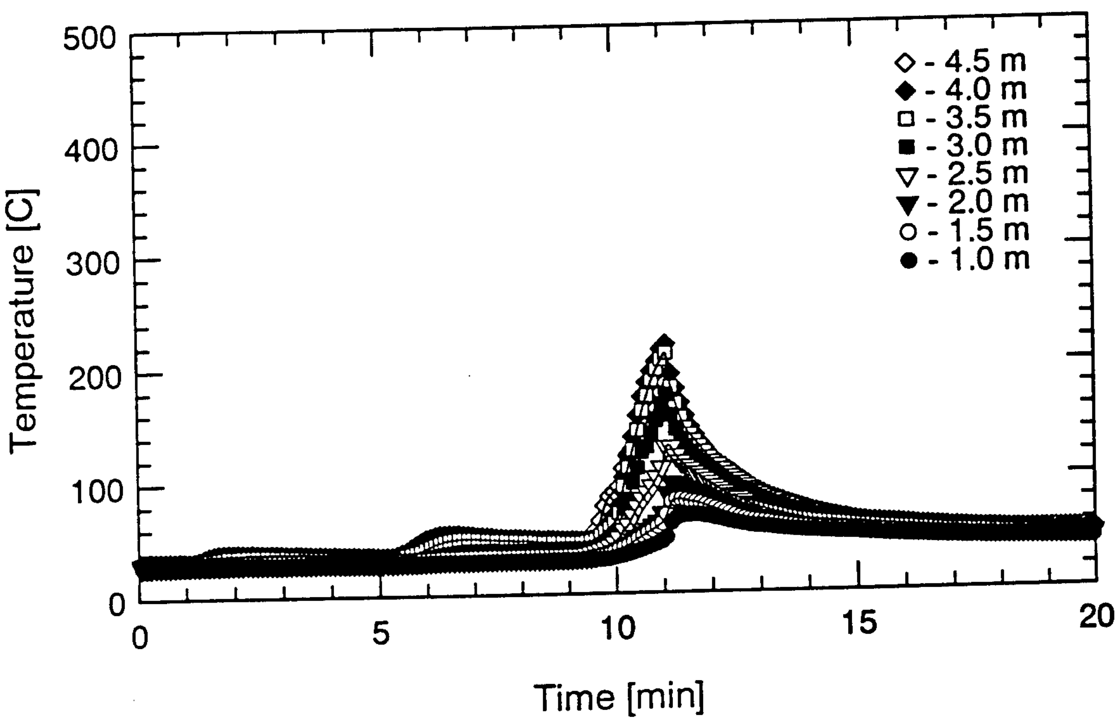

Agent and HF Concentrations
TEST #15



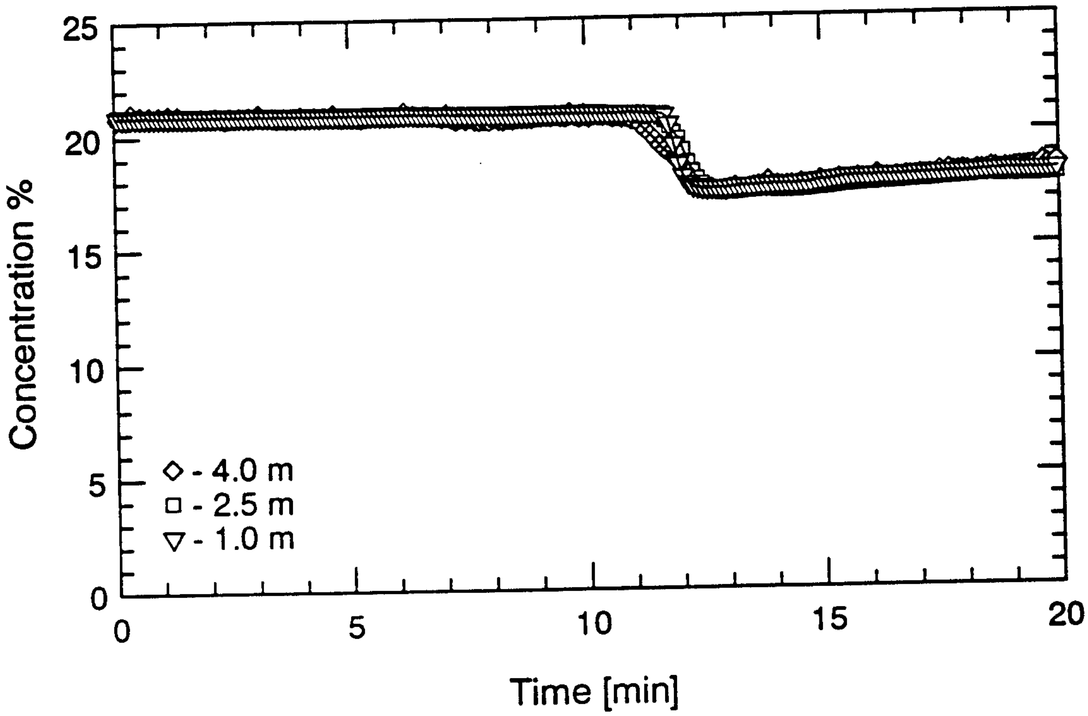



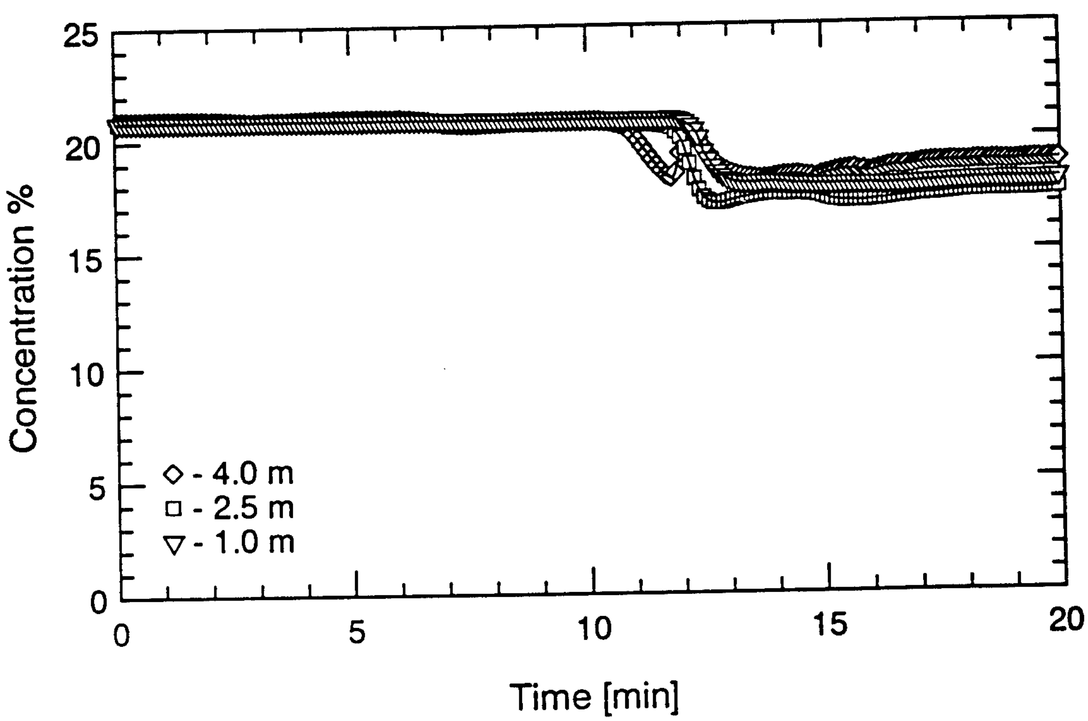

Pressure Measurements
TEST #15



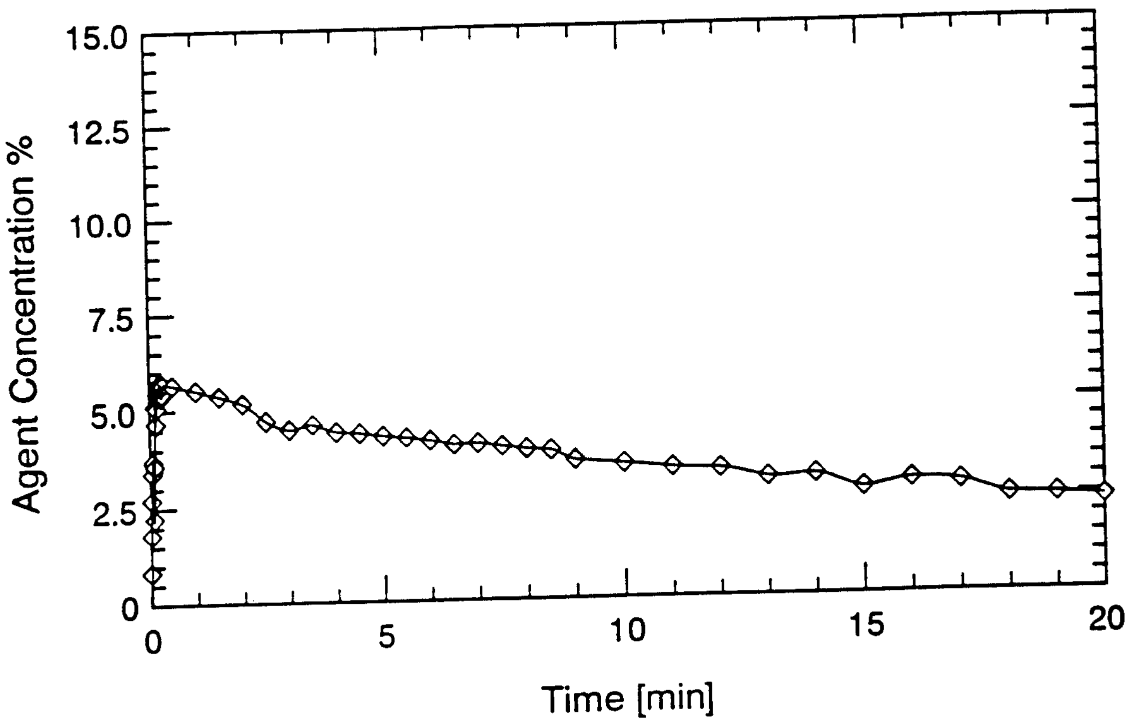



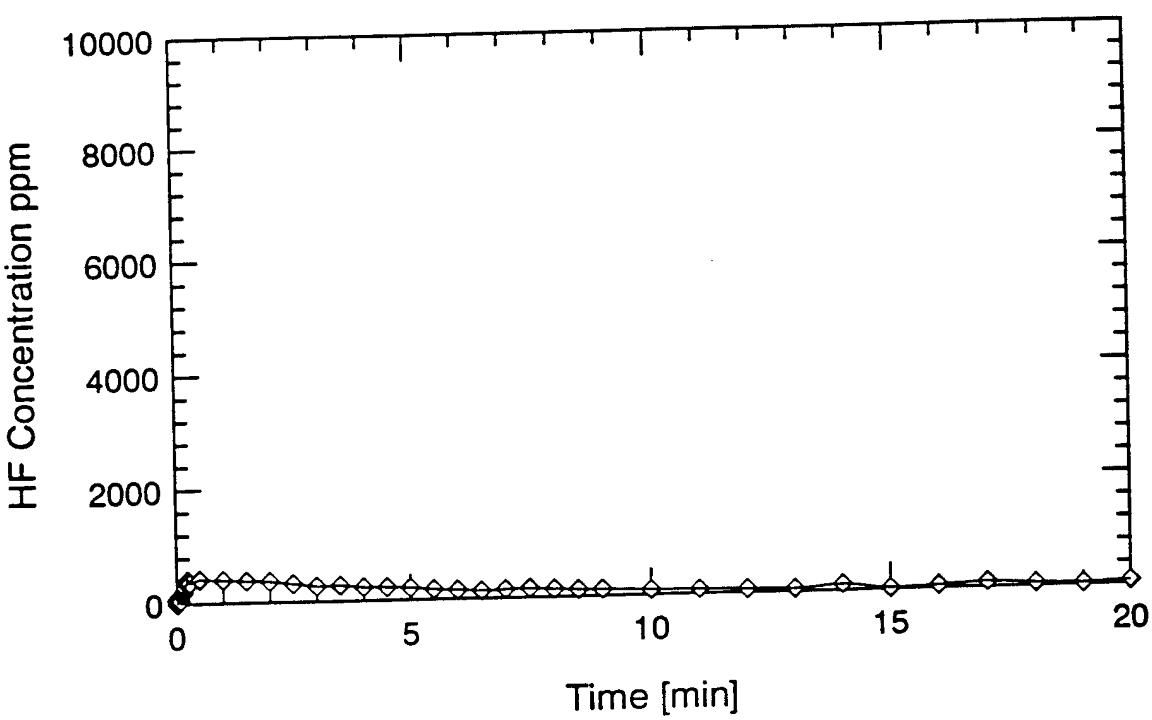

Compartment Temperatures
TEST #16



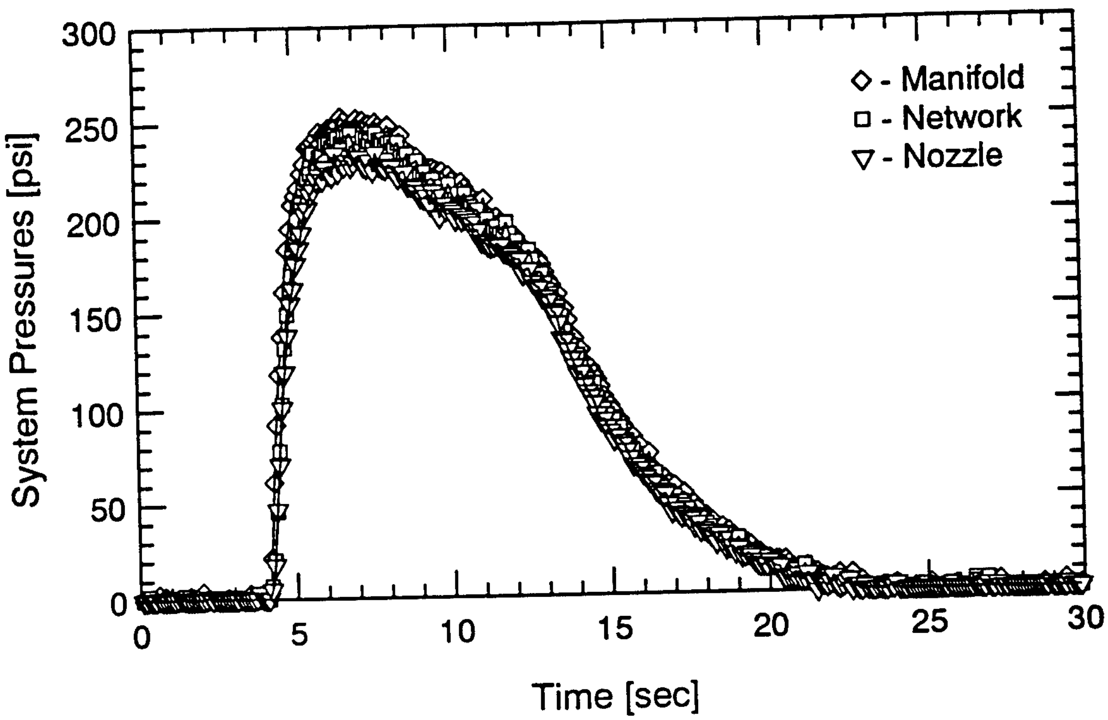



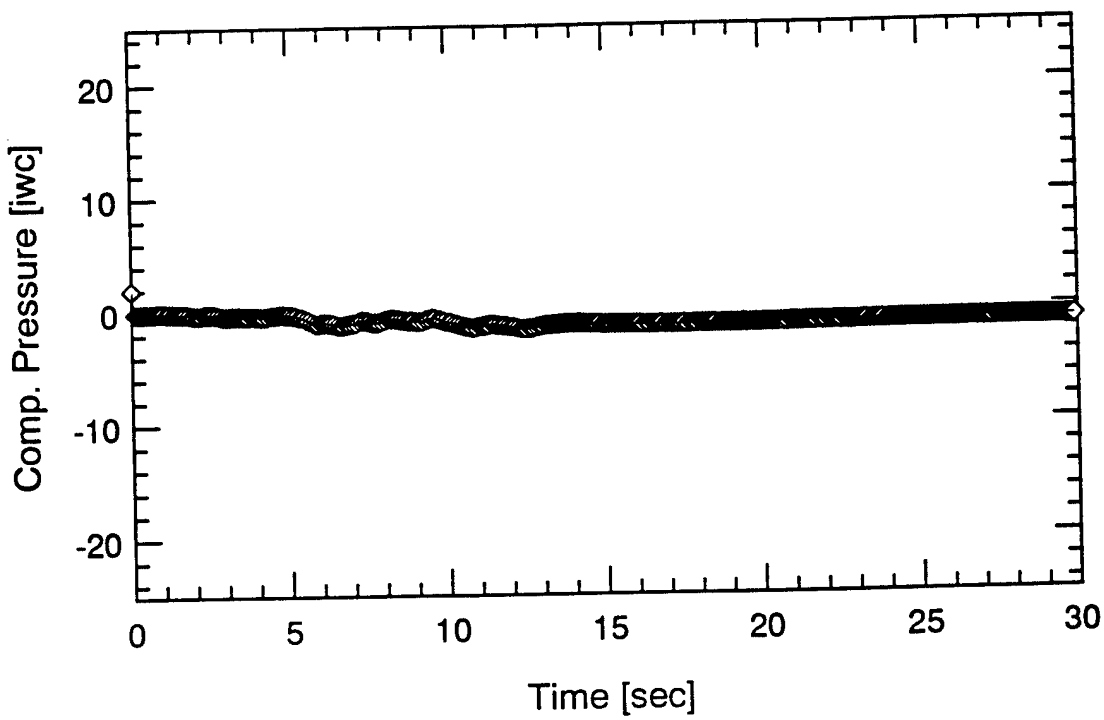

Oxygen Concentrations
TEST #16



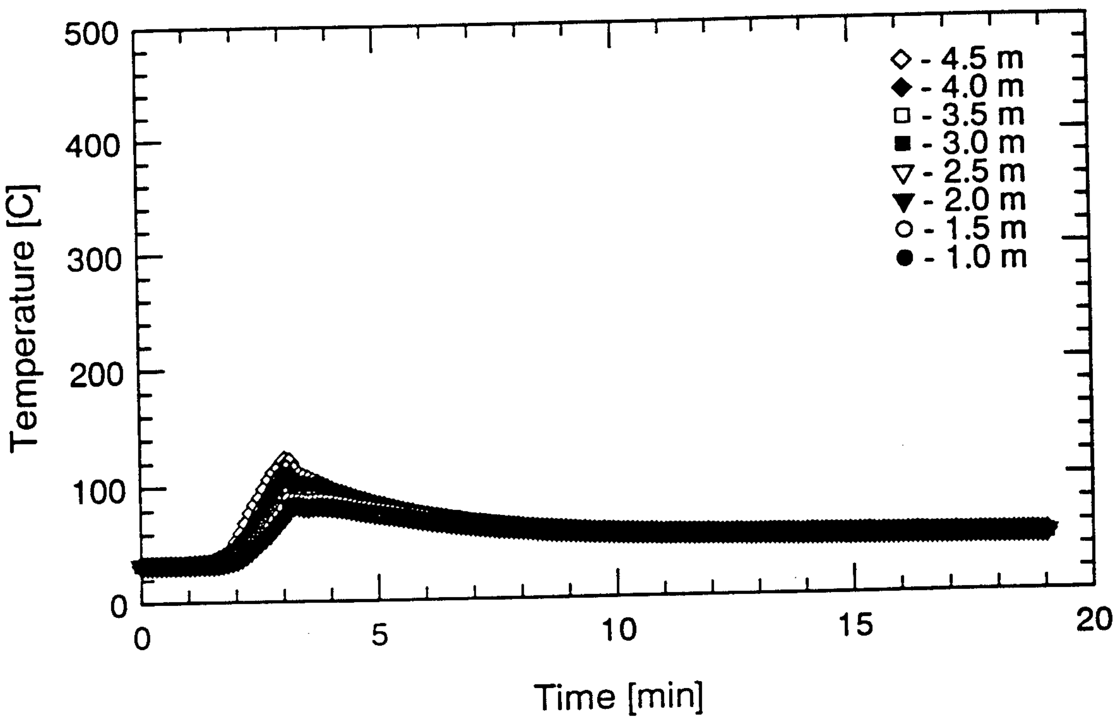



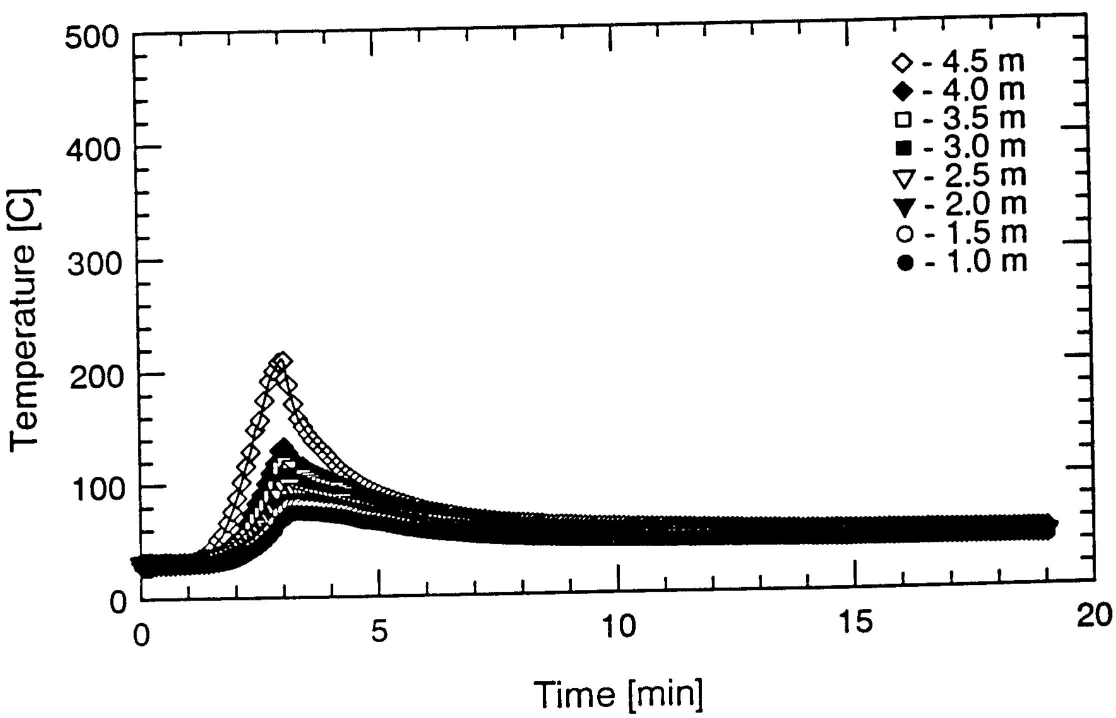

Agent and HF Concentrations
TEST #16



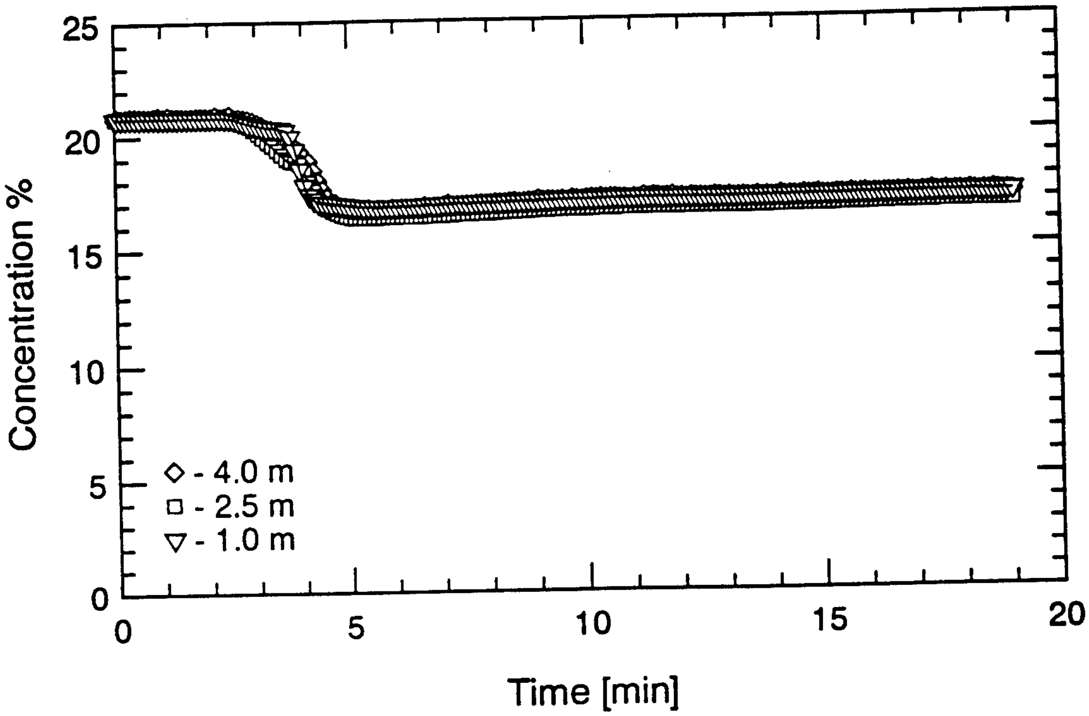



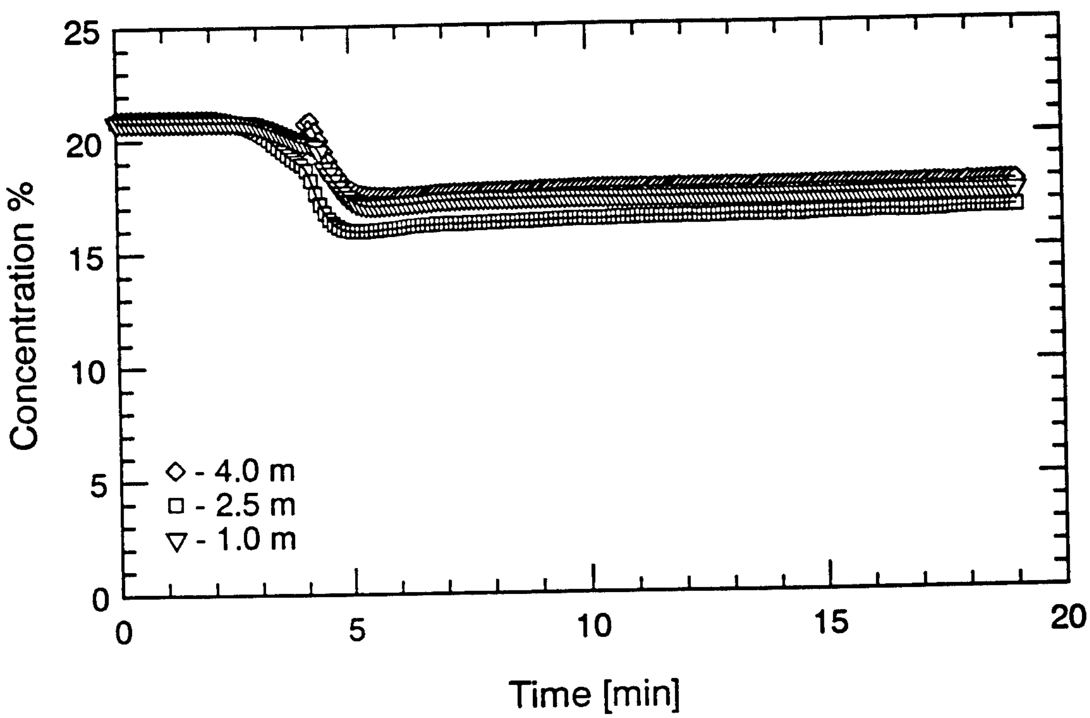

Pressure Measurements
TEST #16



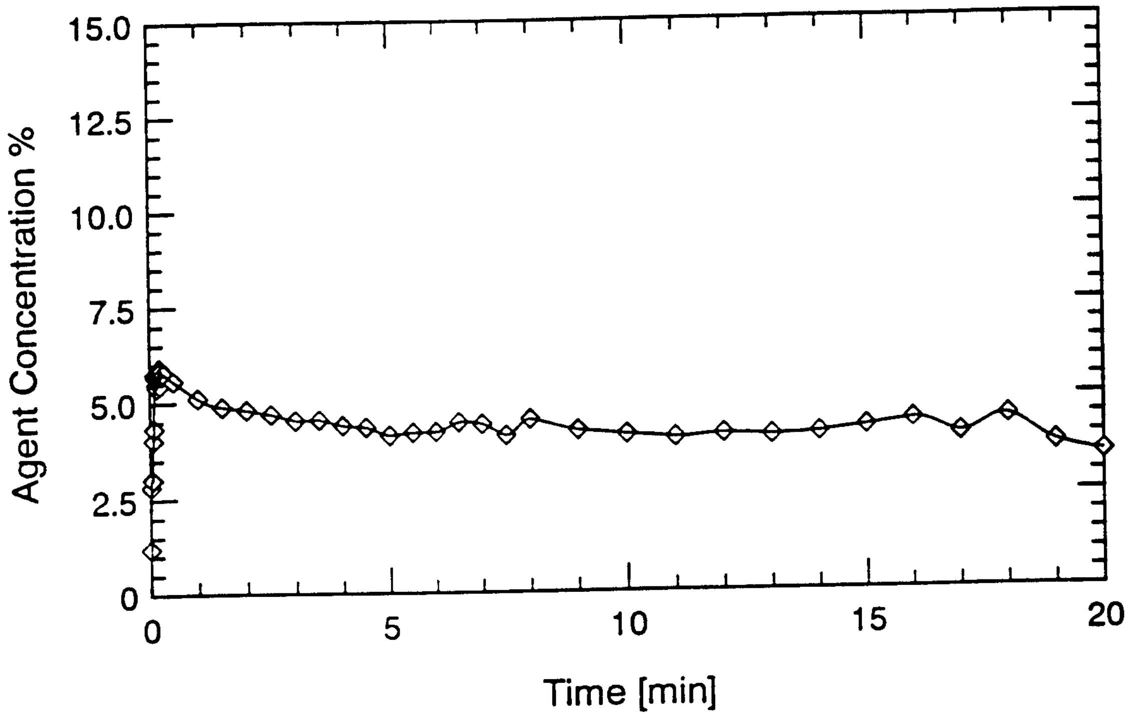



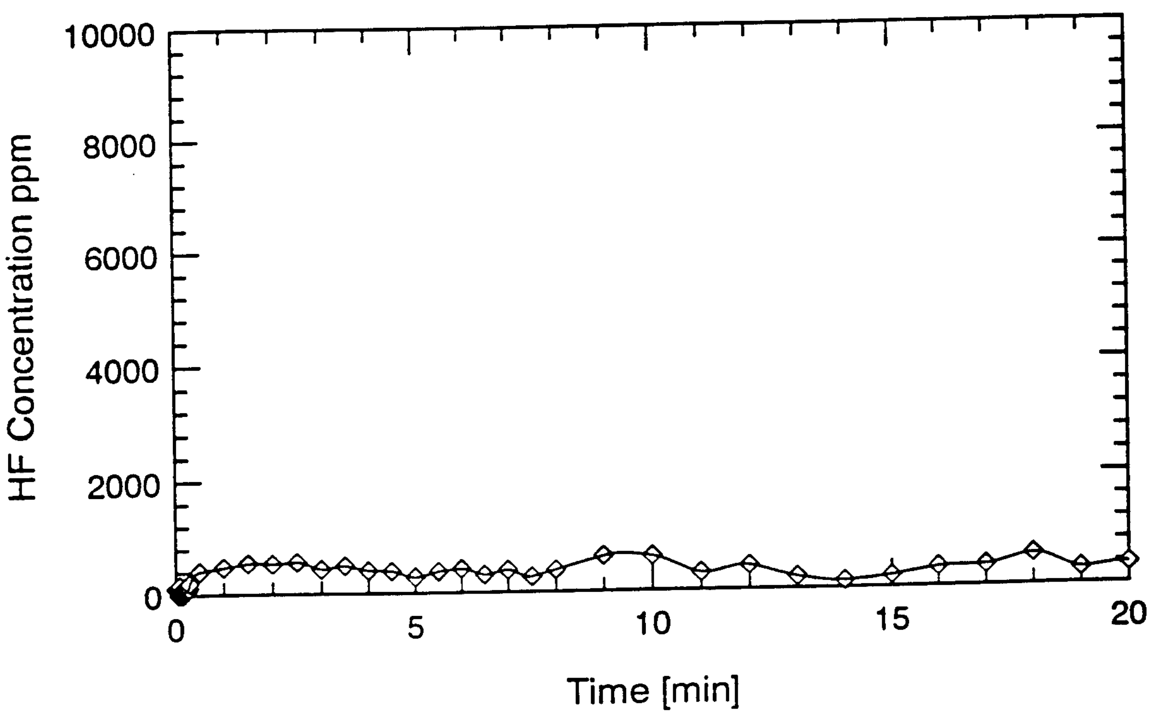

Compartment Temperatures
TEST #17



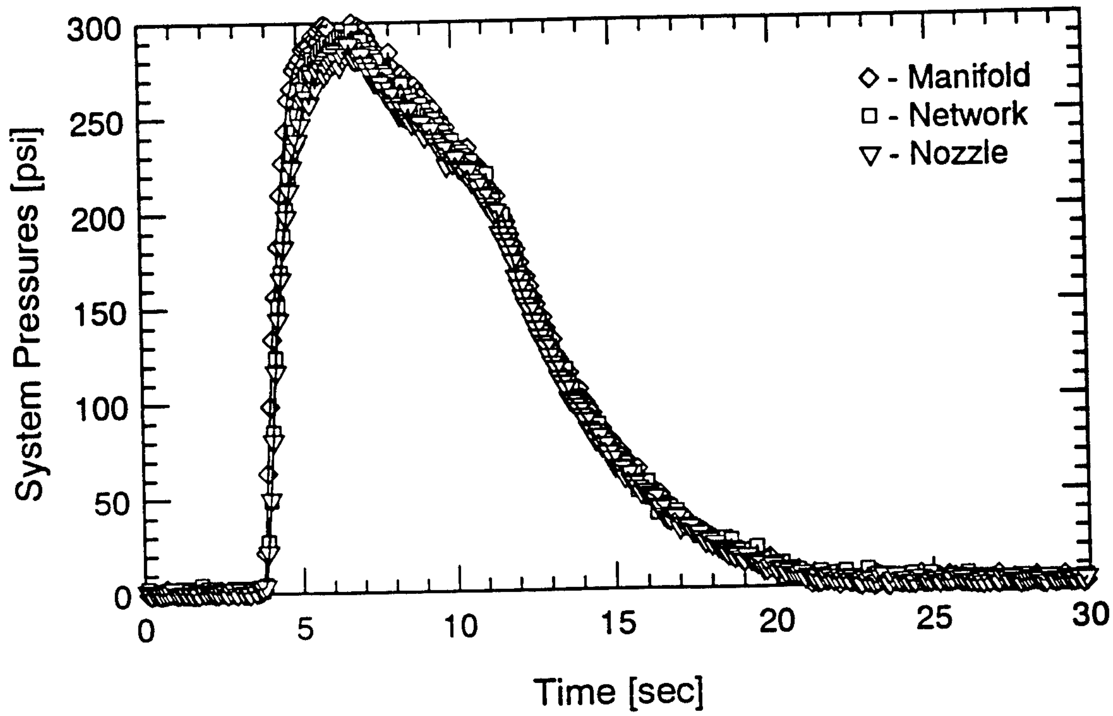



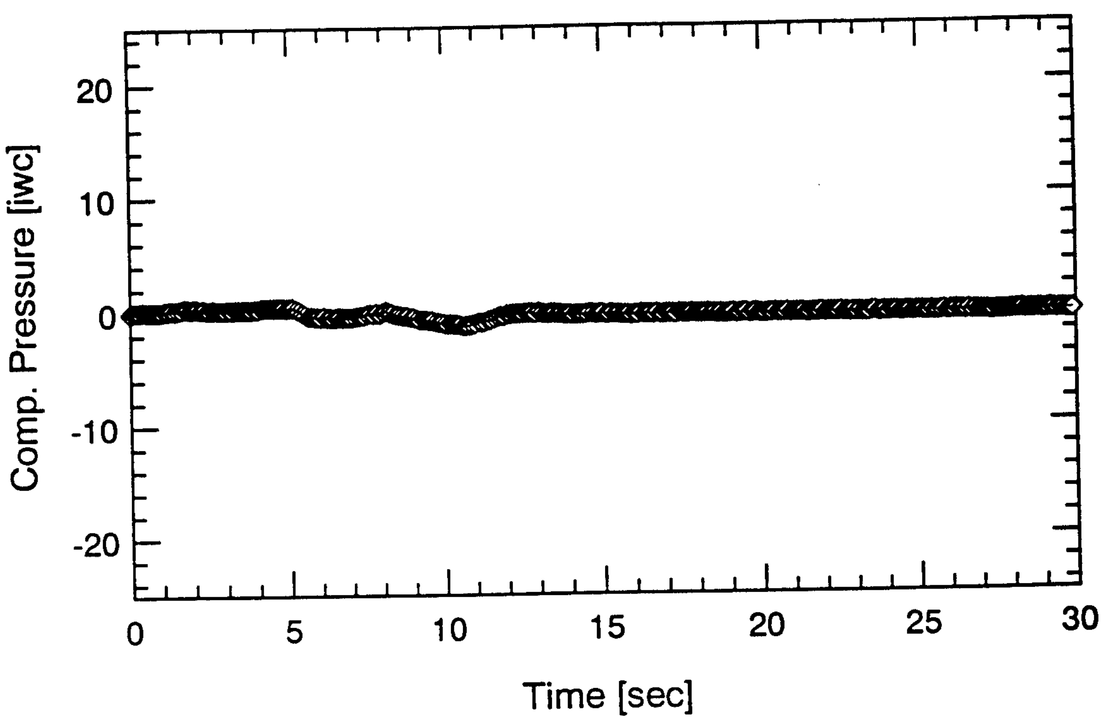

Oxygen Concentrations
TEST #17



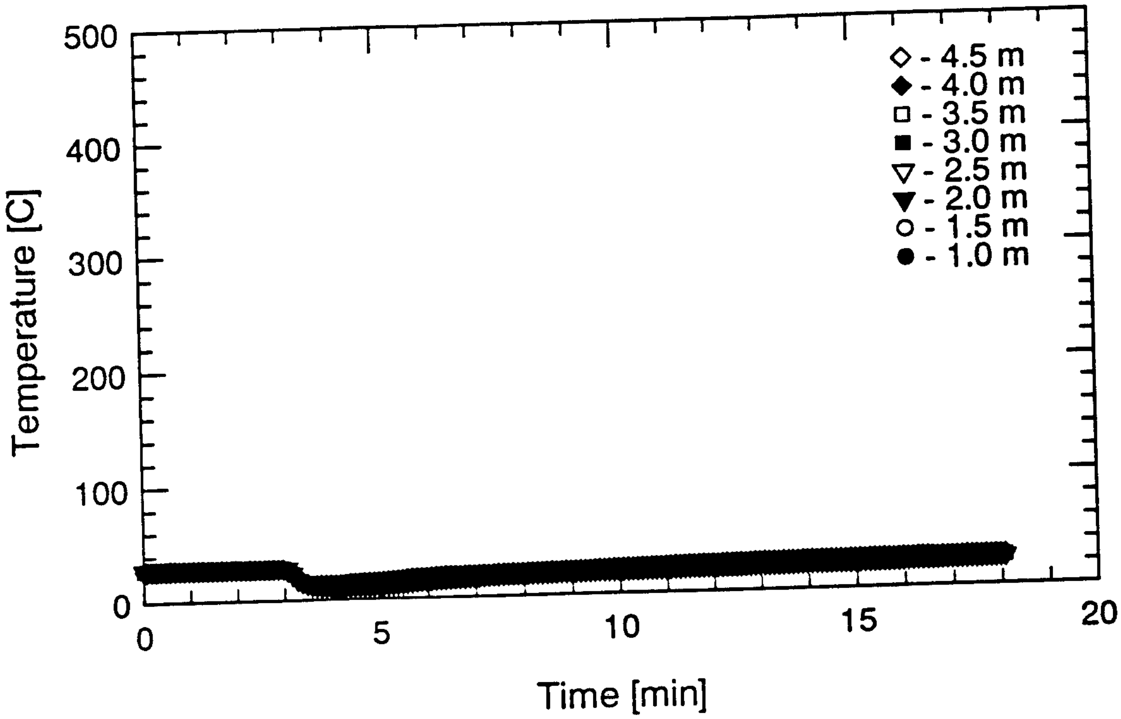



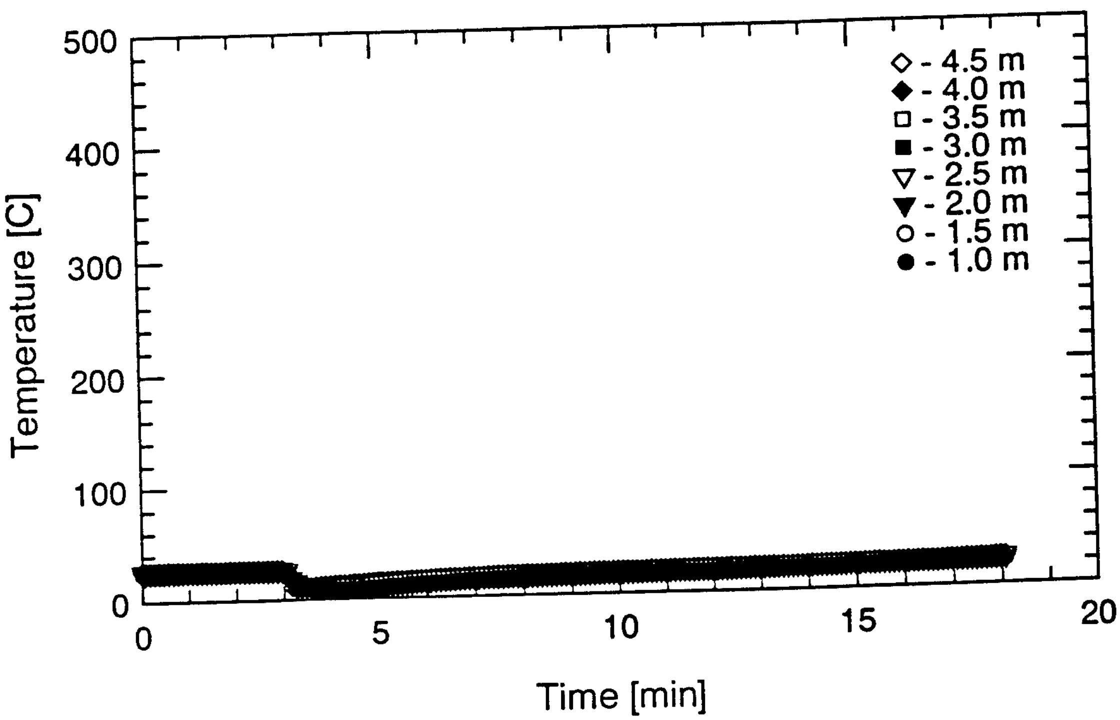

Agent and HF Concentrations
TEST #17



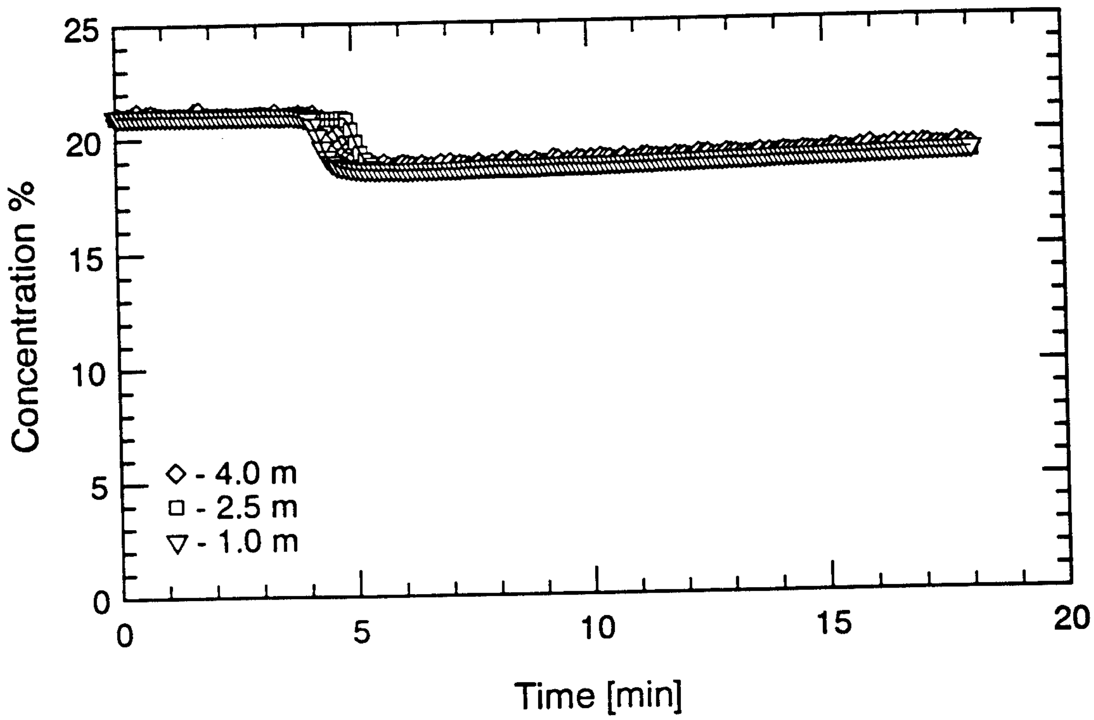



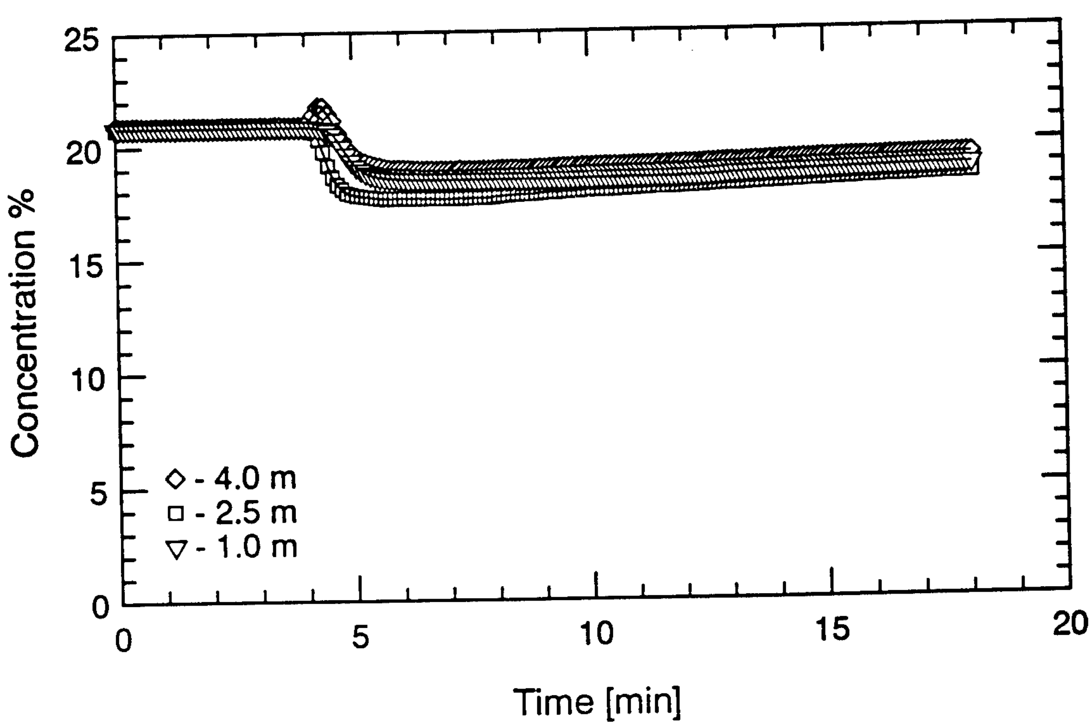

Pressure Measurements
TEST #17



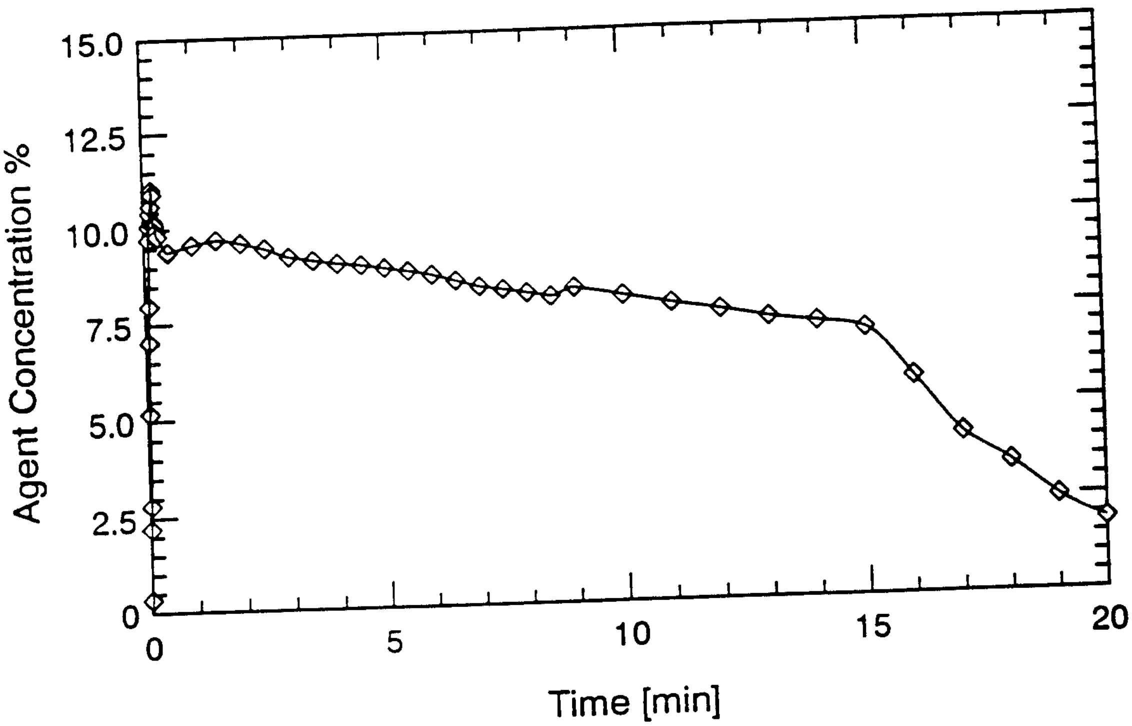



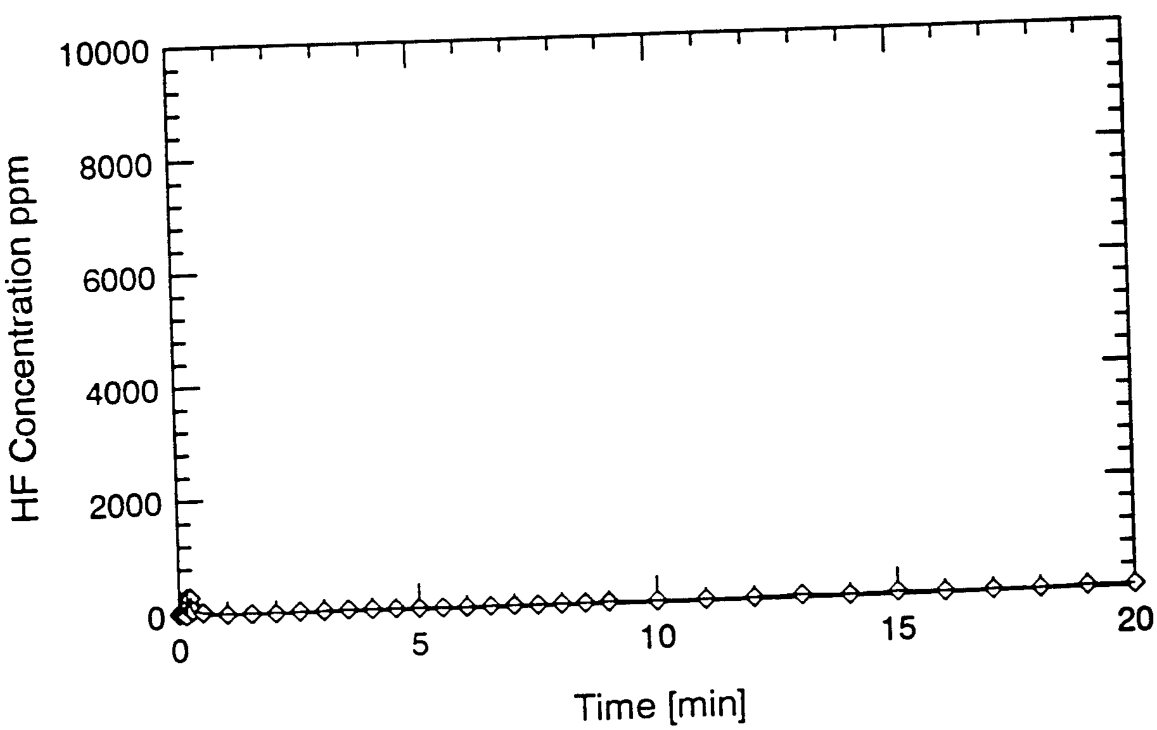

Compartment Temperatures
TEST #18



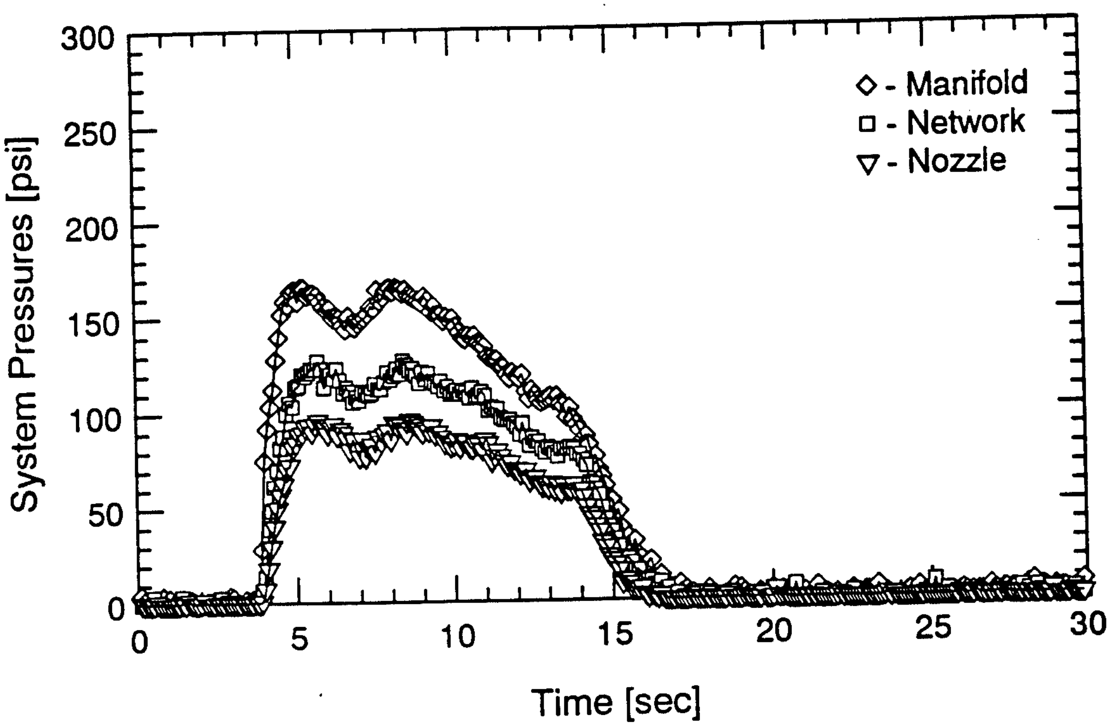



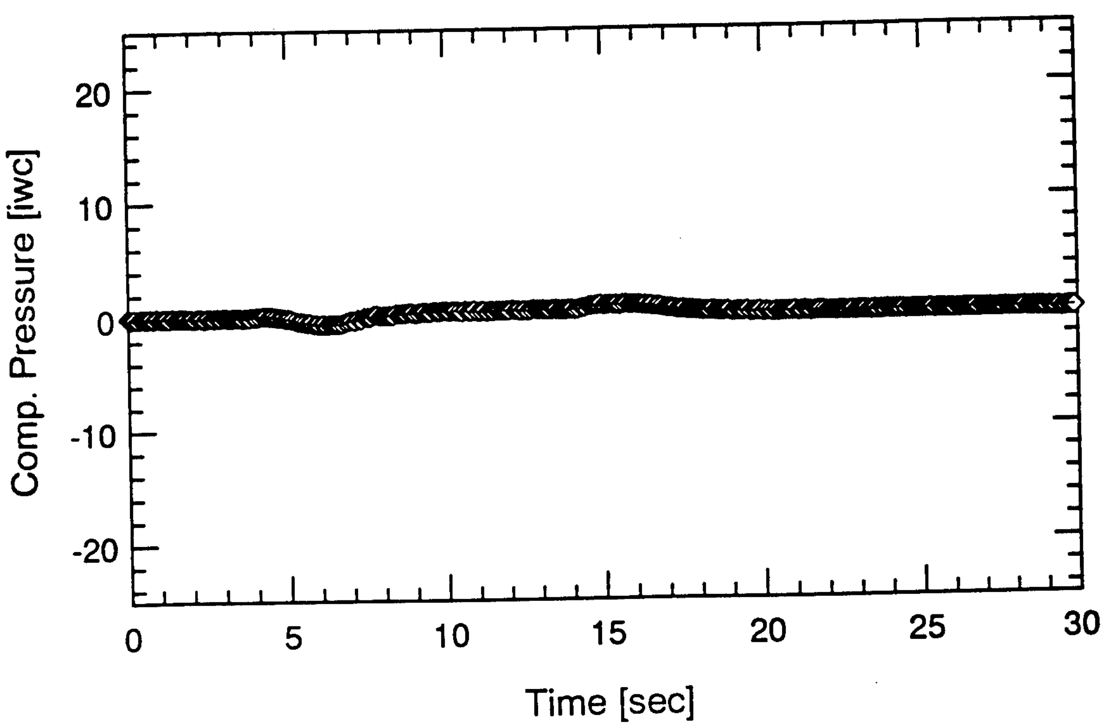

Oxygen Concentrations
TEST #18



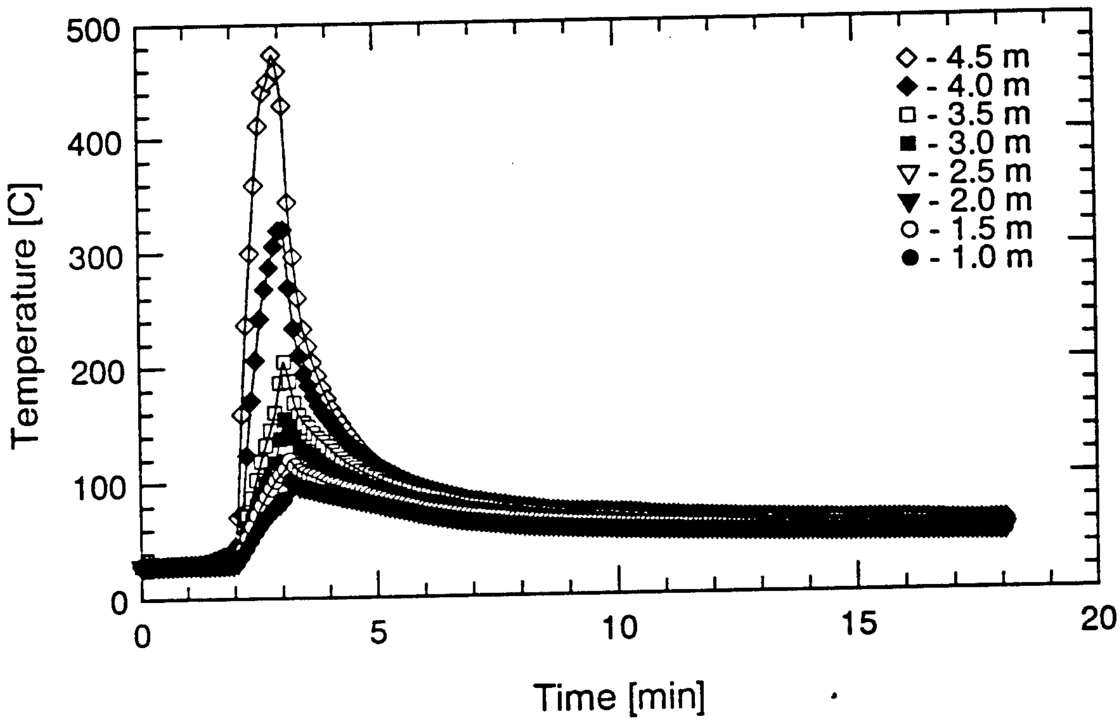



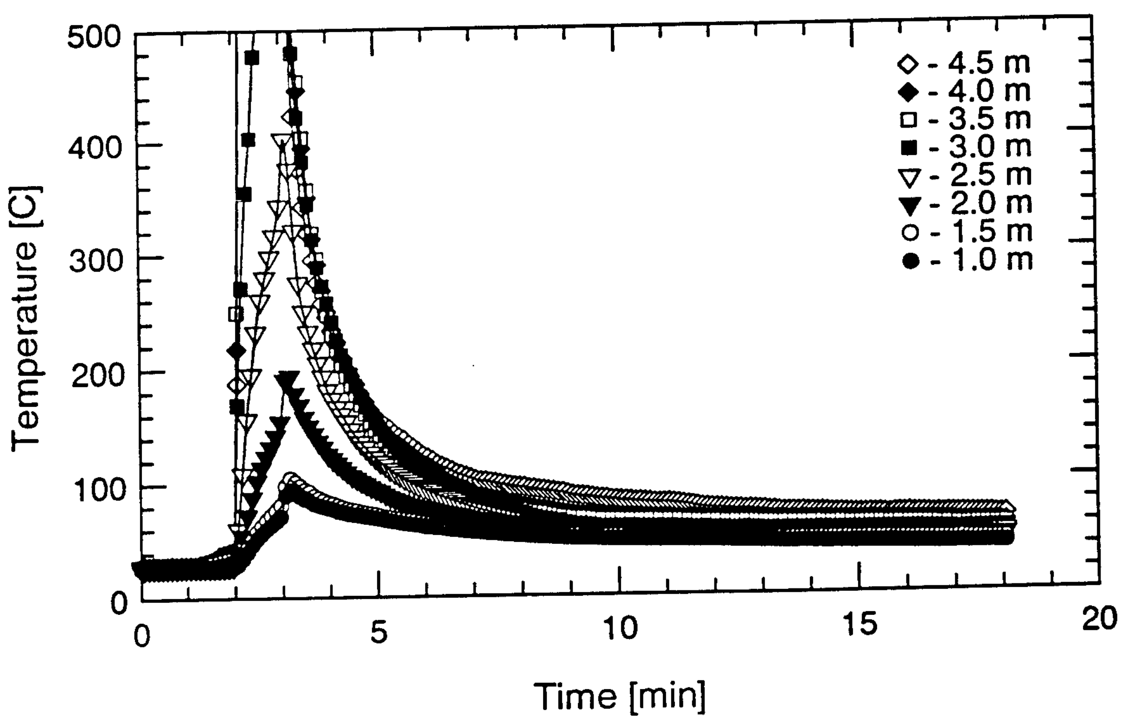

Agent and HF Concentrations
TEST #18



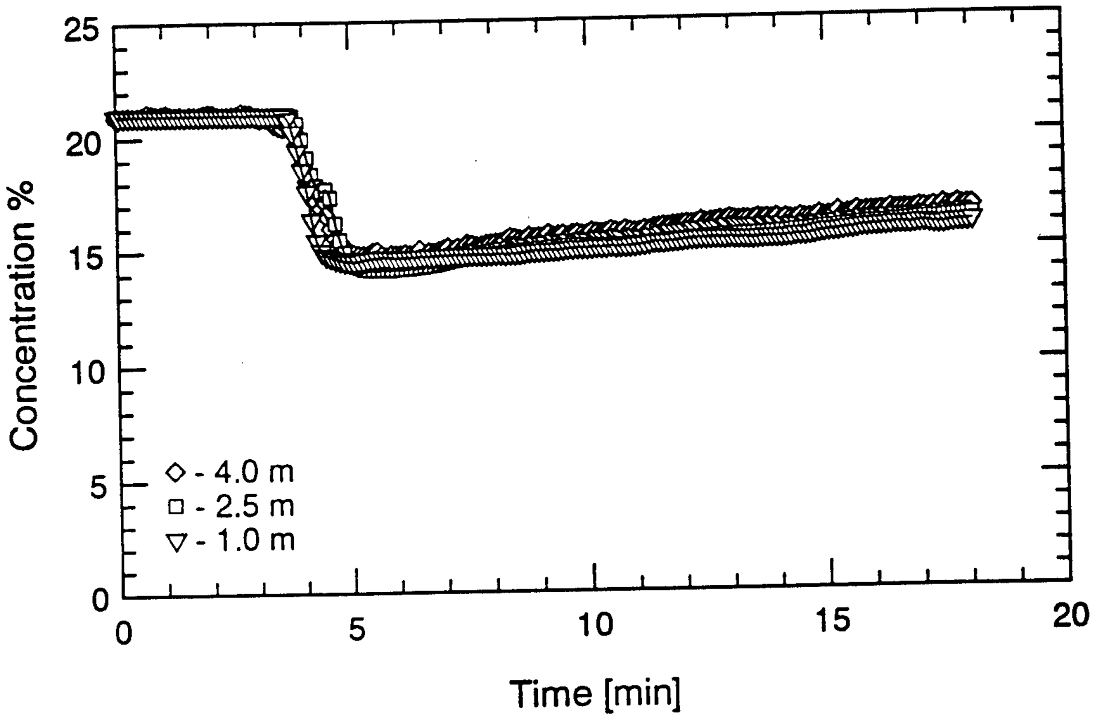



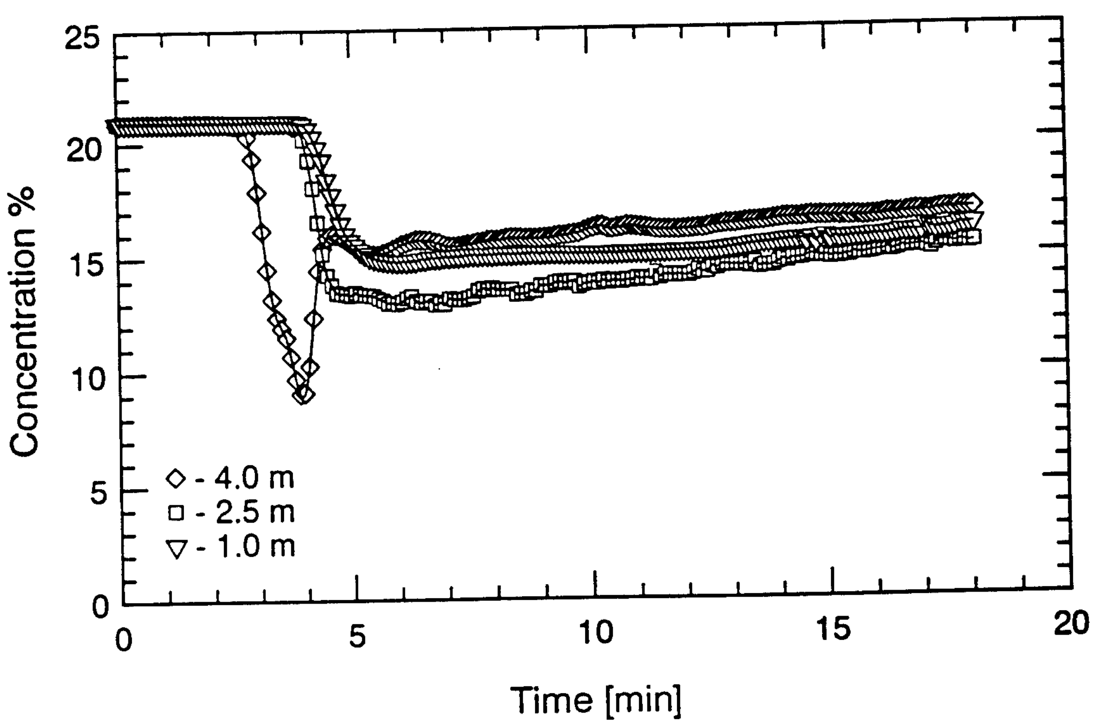

Pressure Measurements
TEST #18



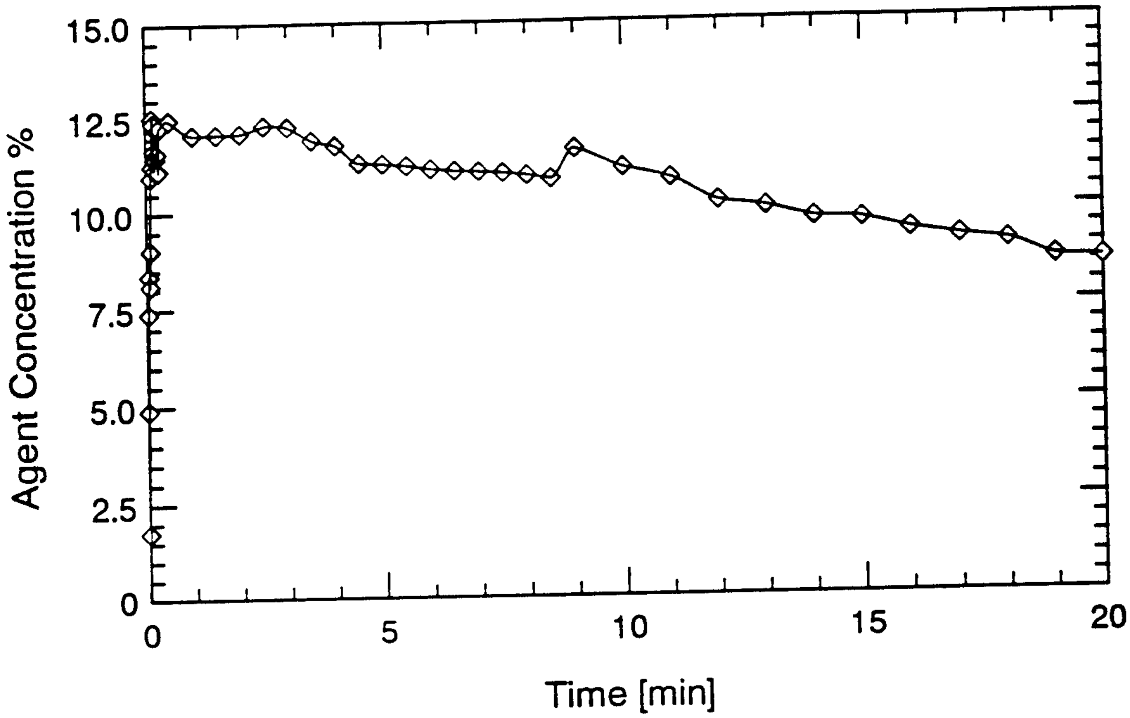



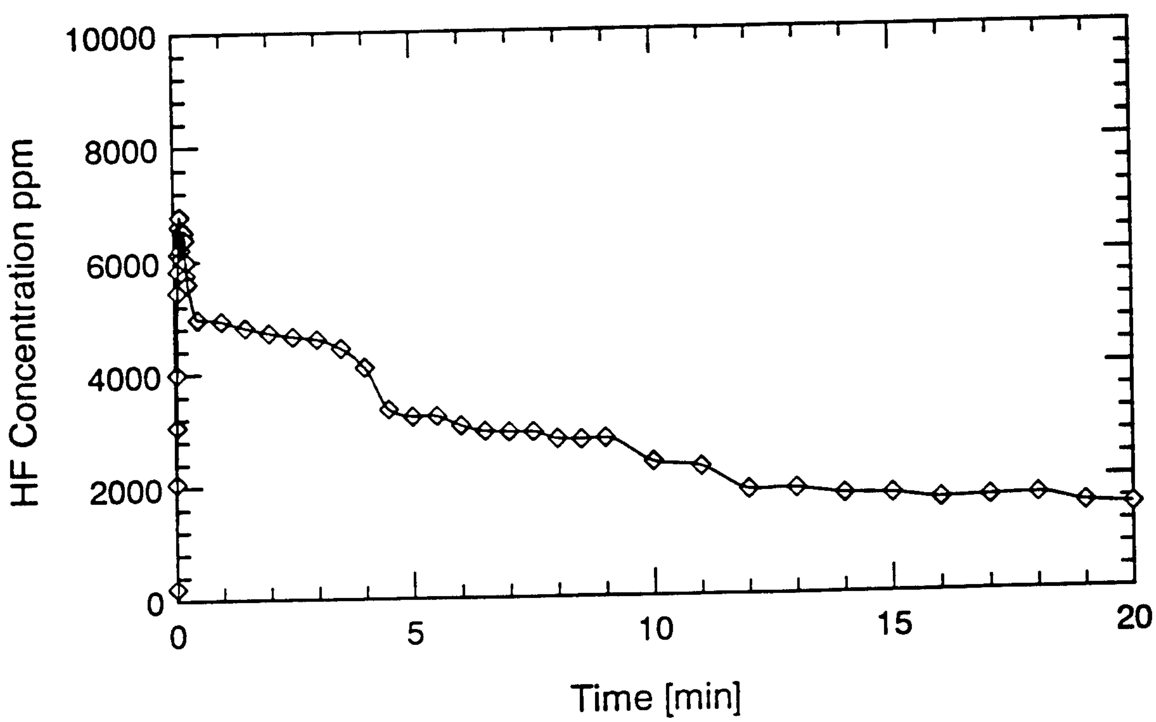

Compartment Temperatures
TEST #19



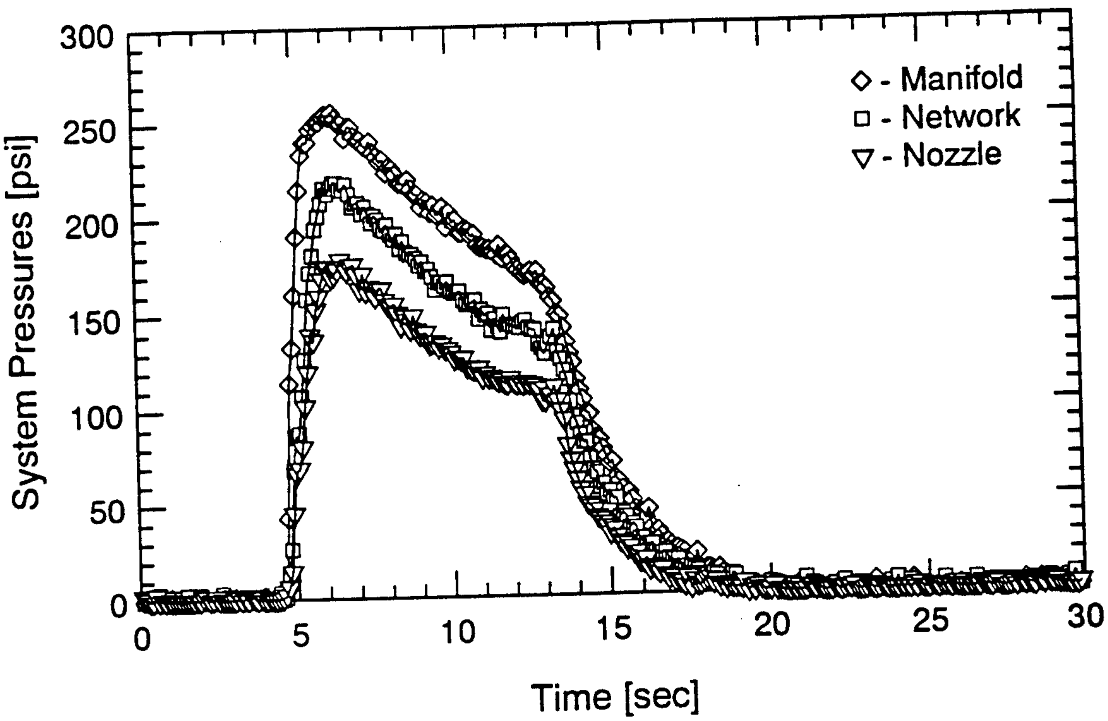



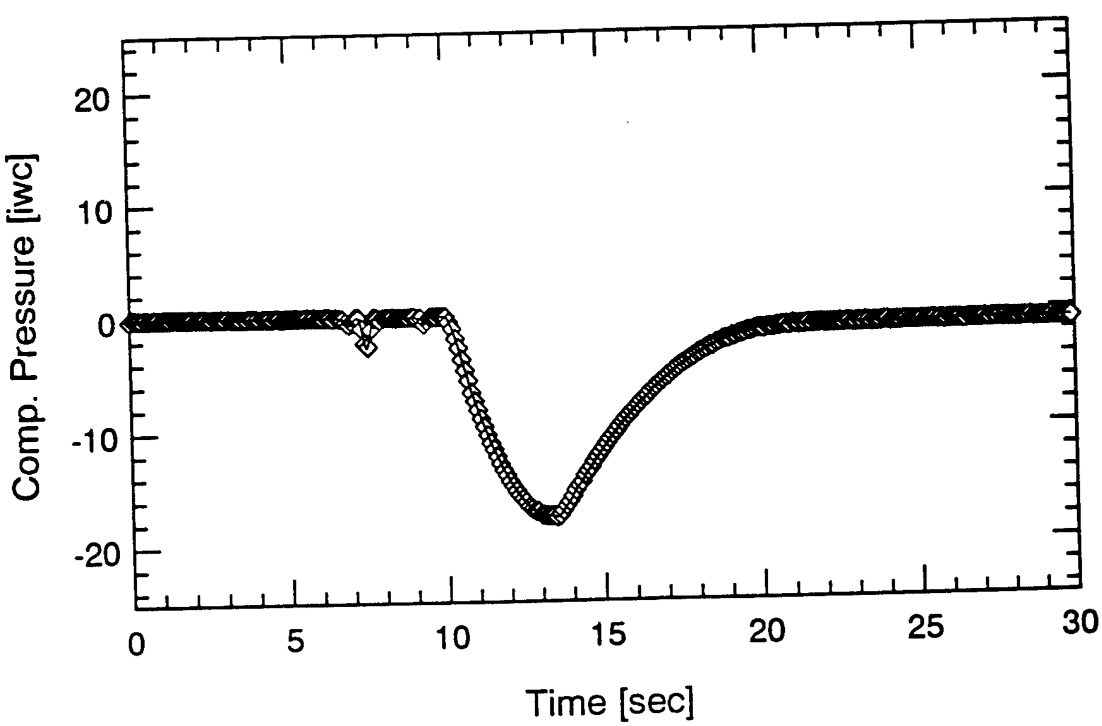

Oxygen Concentrations
TEST #19



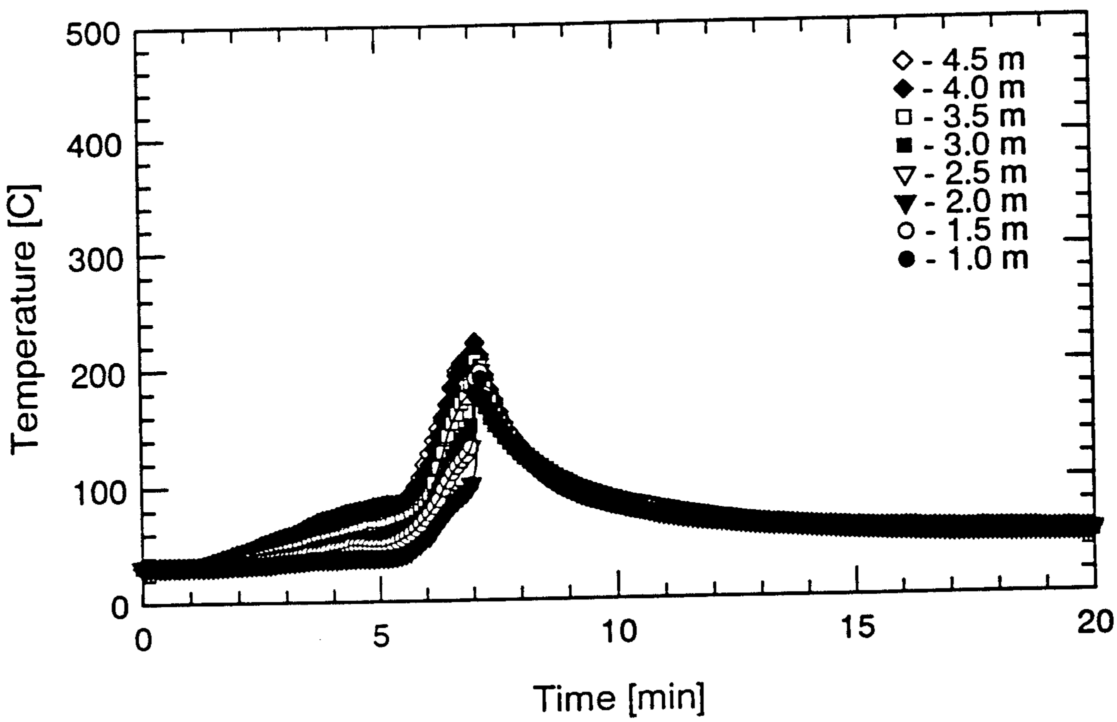



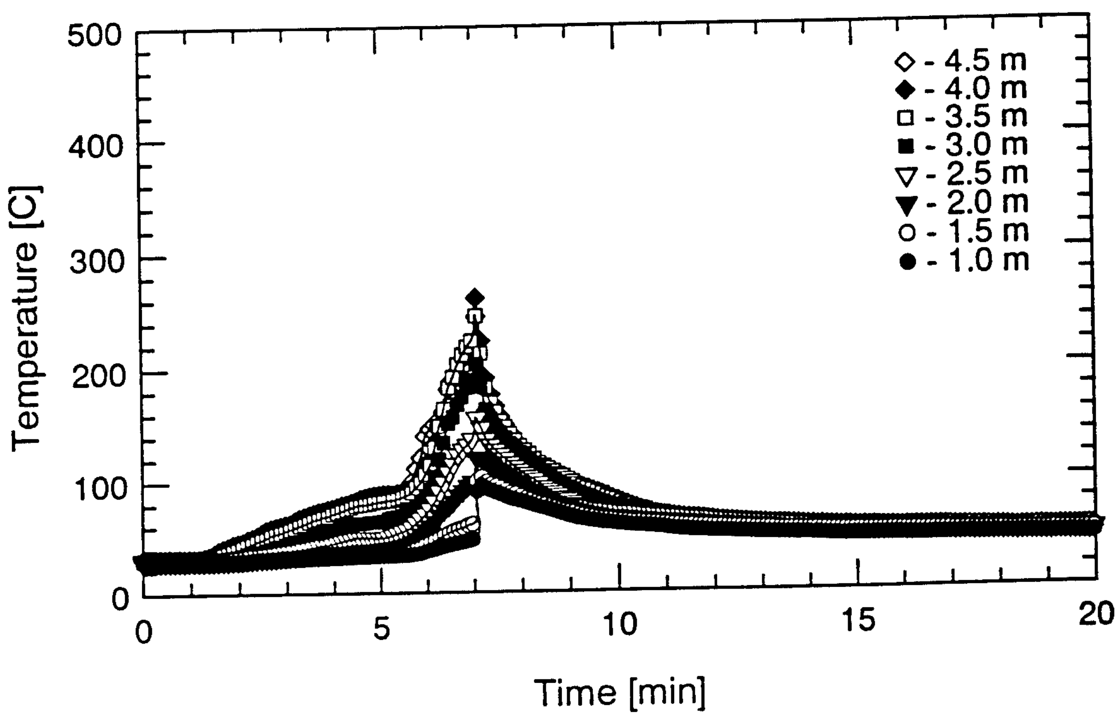

Agent and HF Concentrations
TEST #19



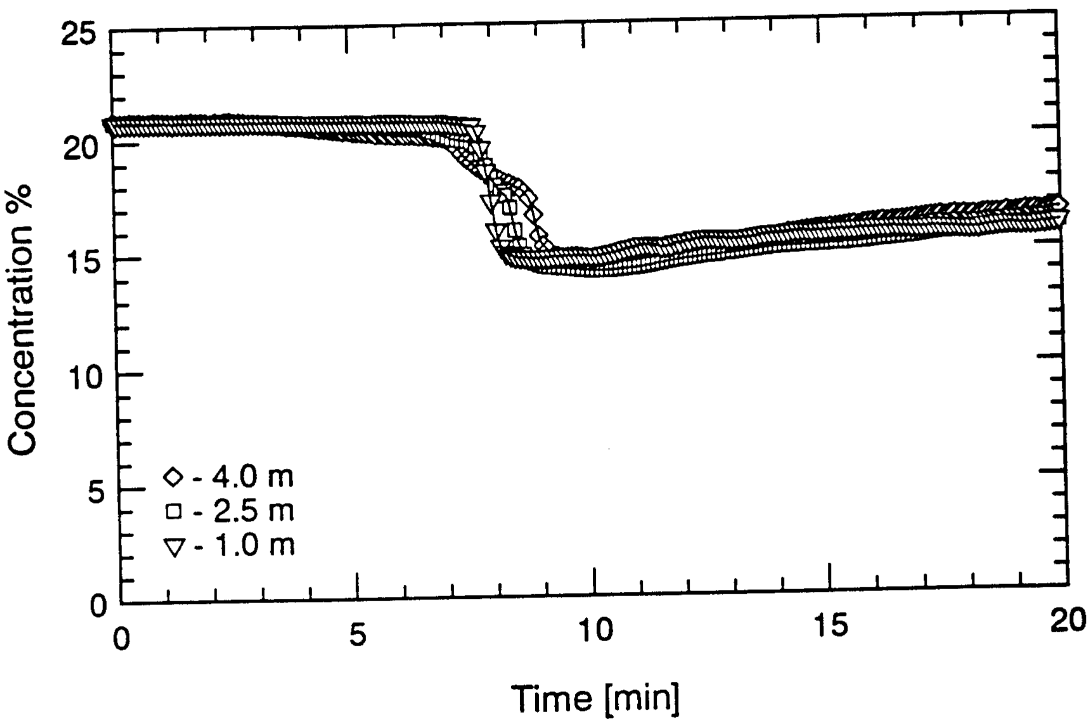



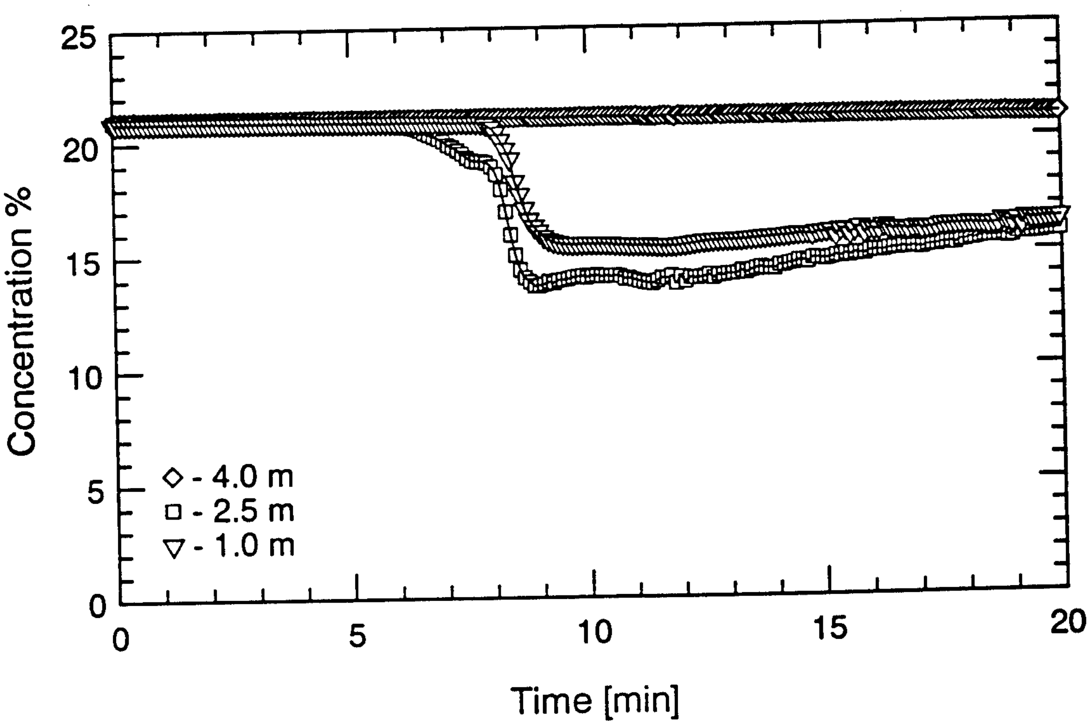

Pressure Measurements
TEST #19



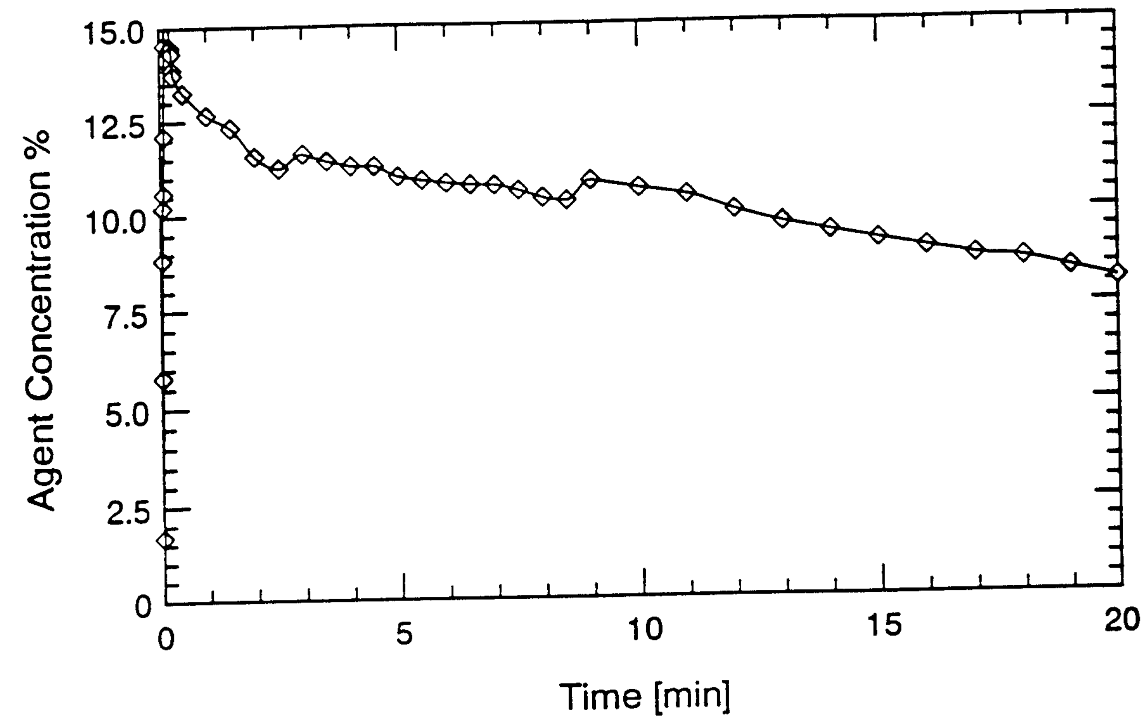



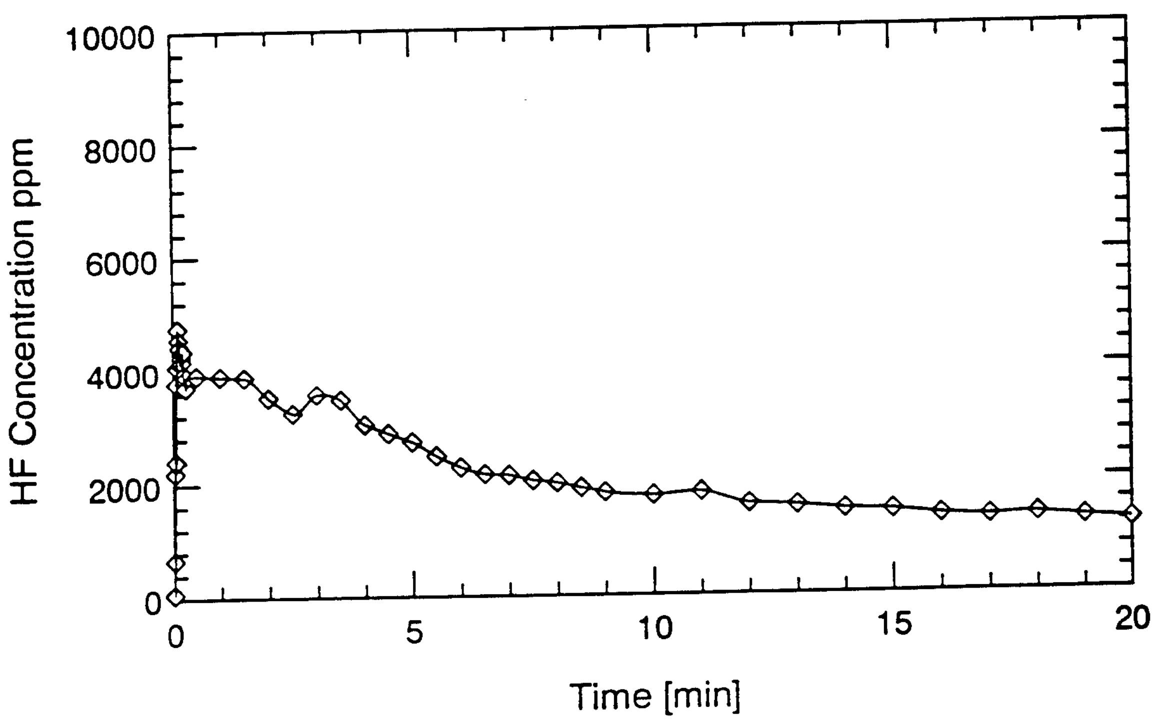

Compartment Temperatures
TEST #20



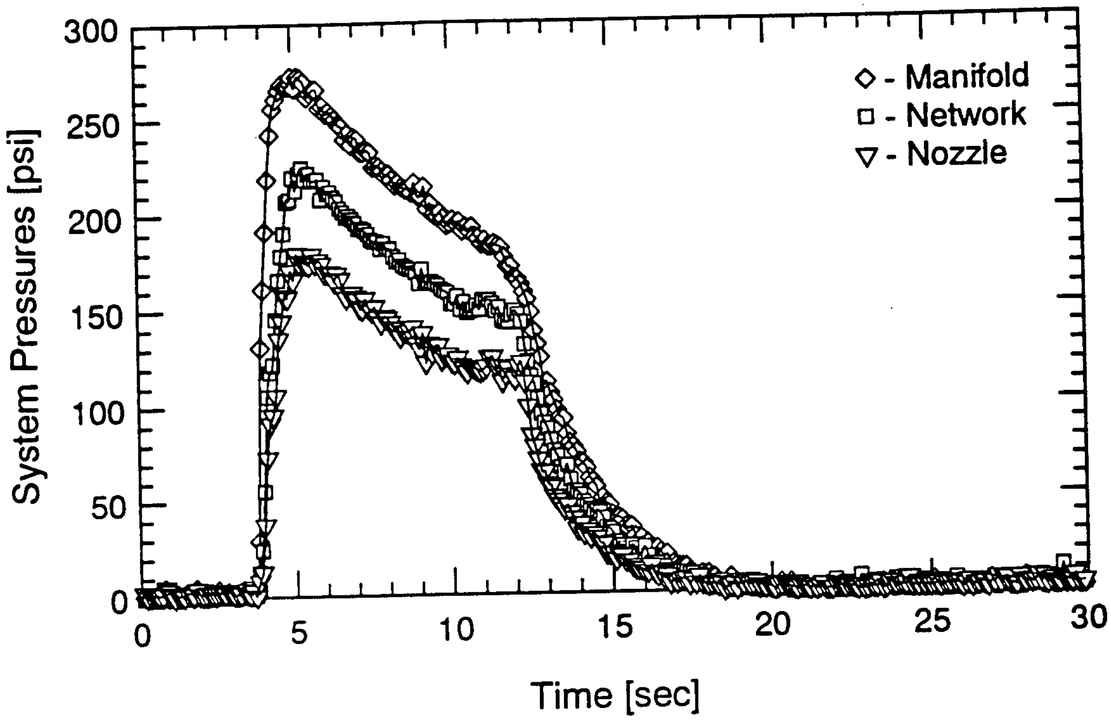



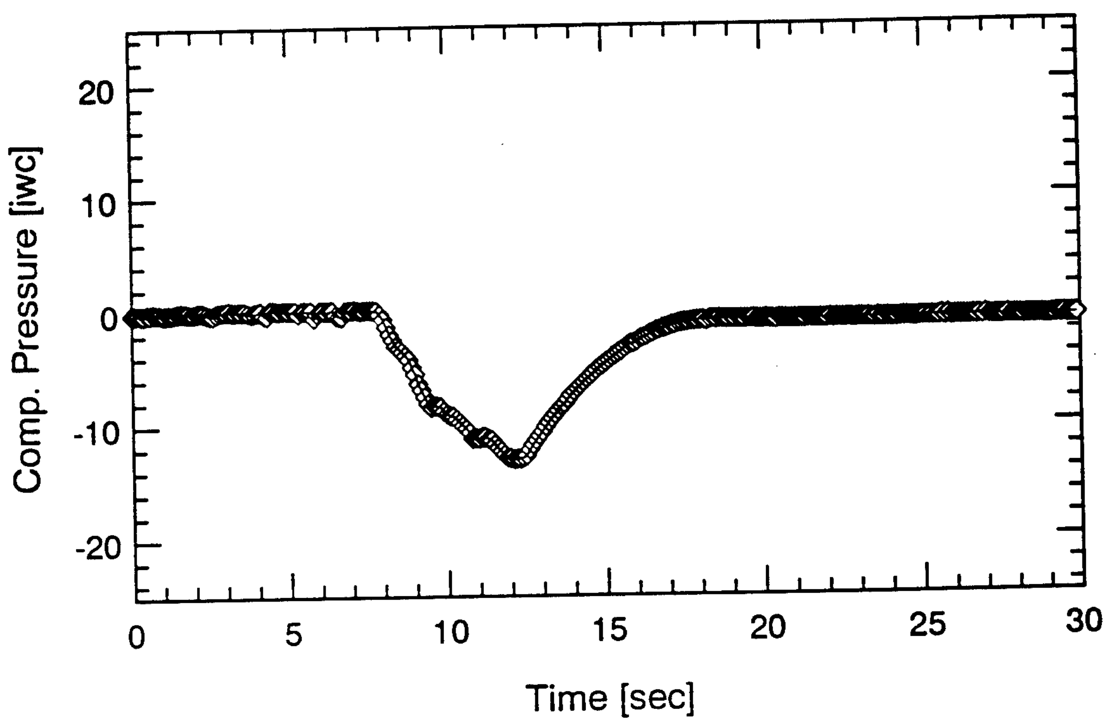

Oxygen Concentrations
TEST #20



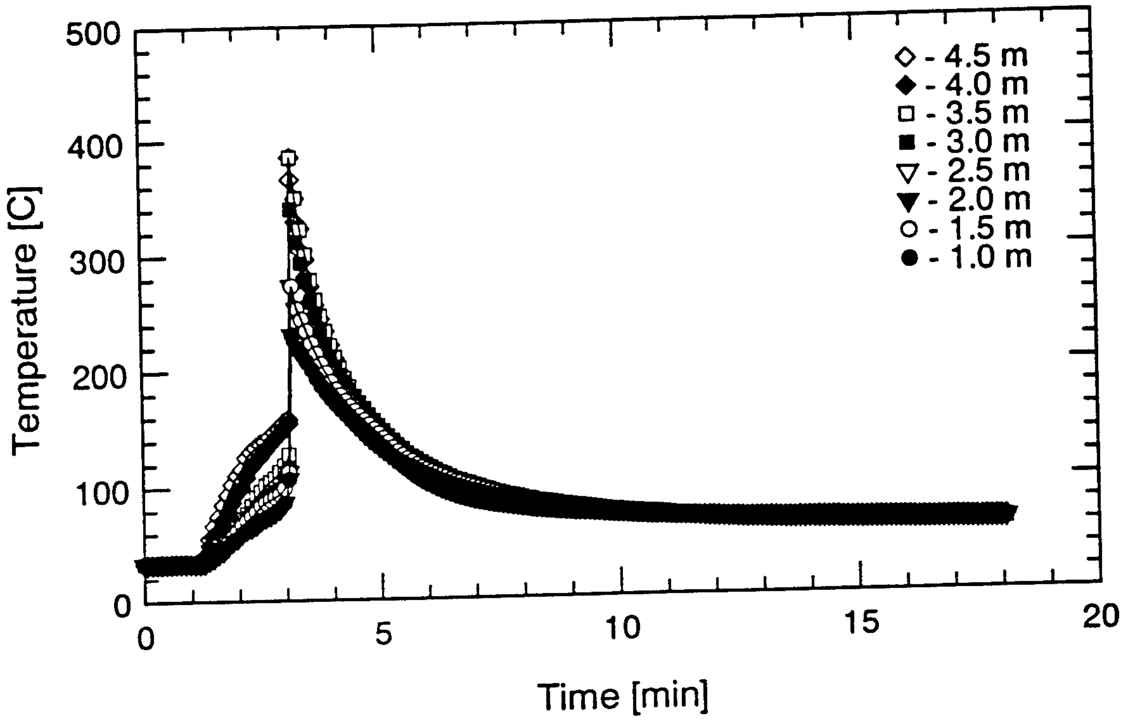



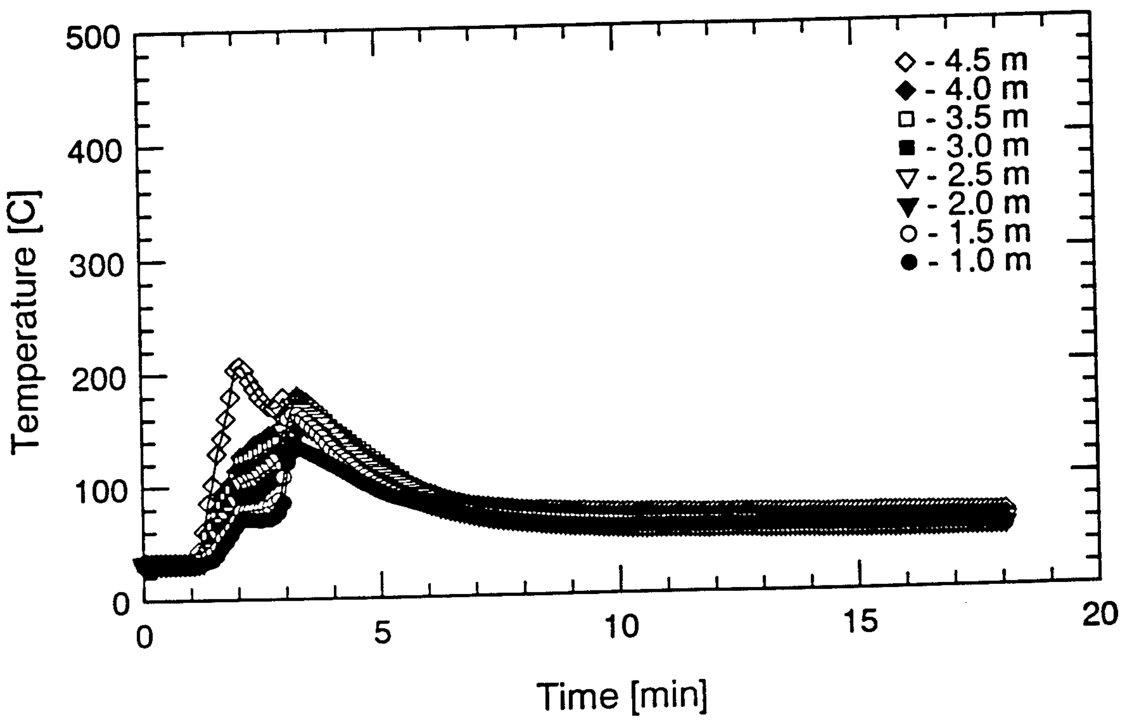

Agent and HF Concentrations
TEST #20



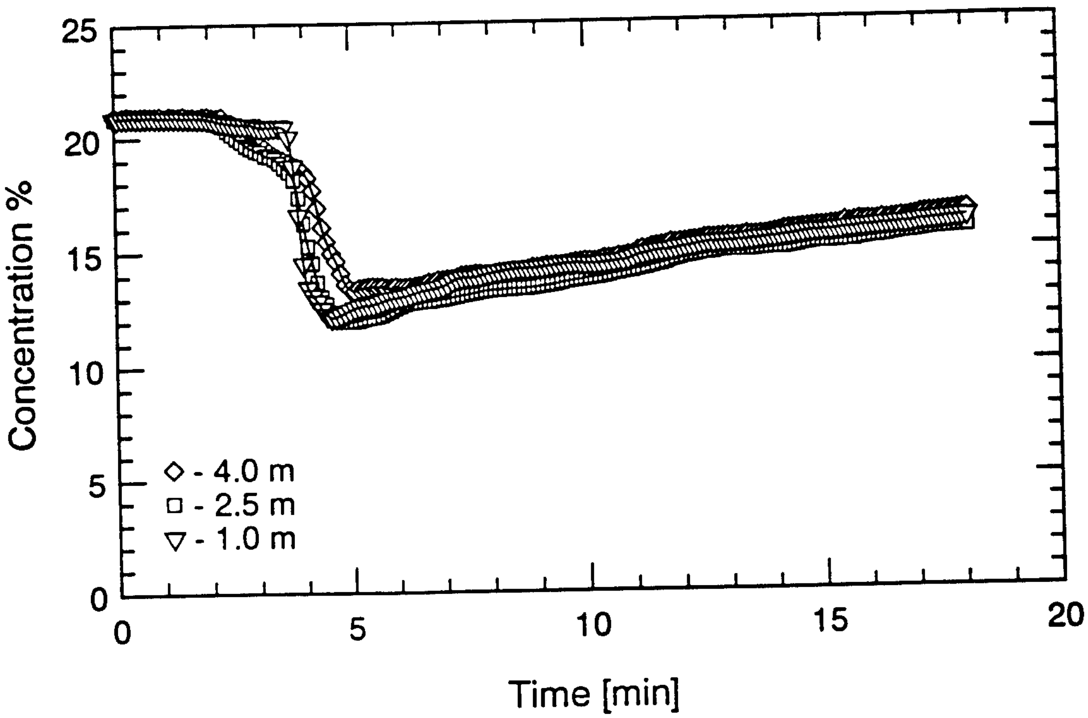



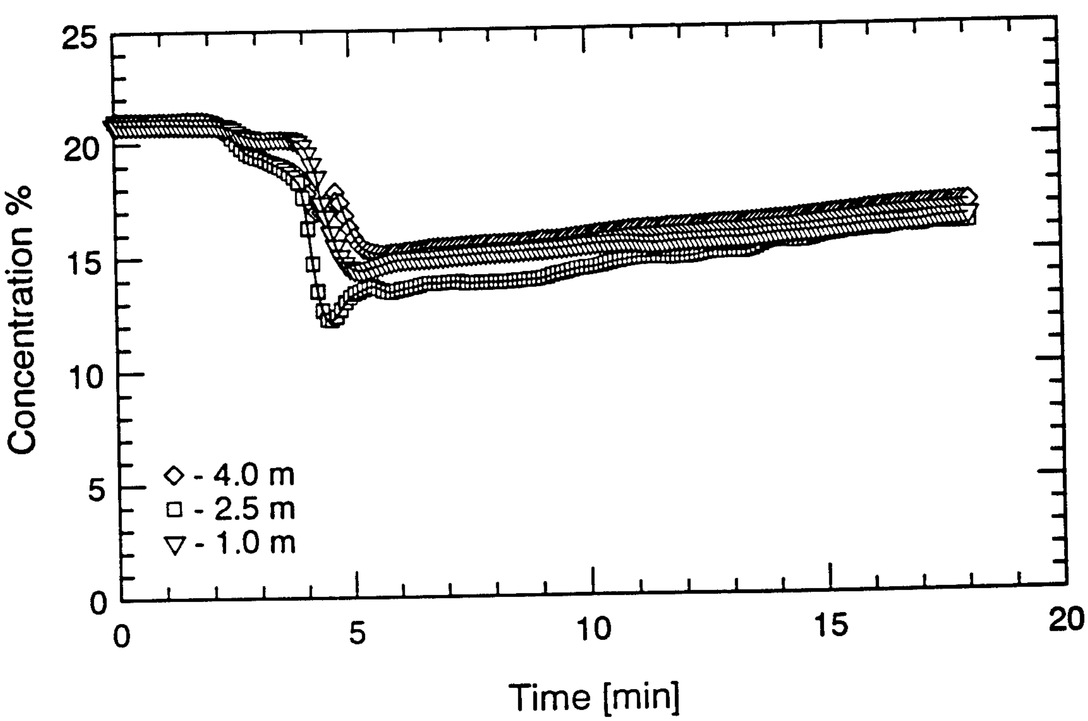

Pressure Measurements
TEST #20



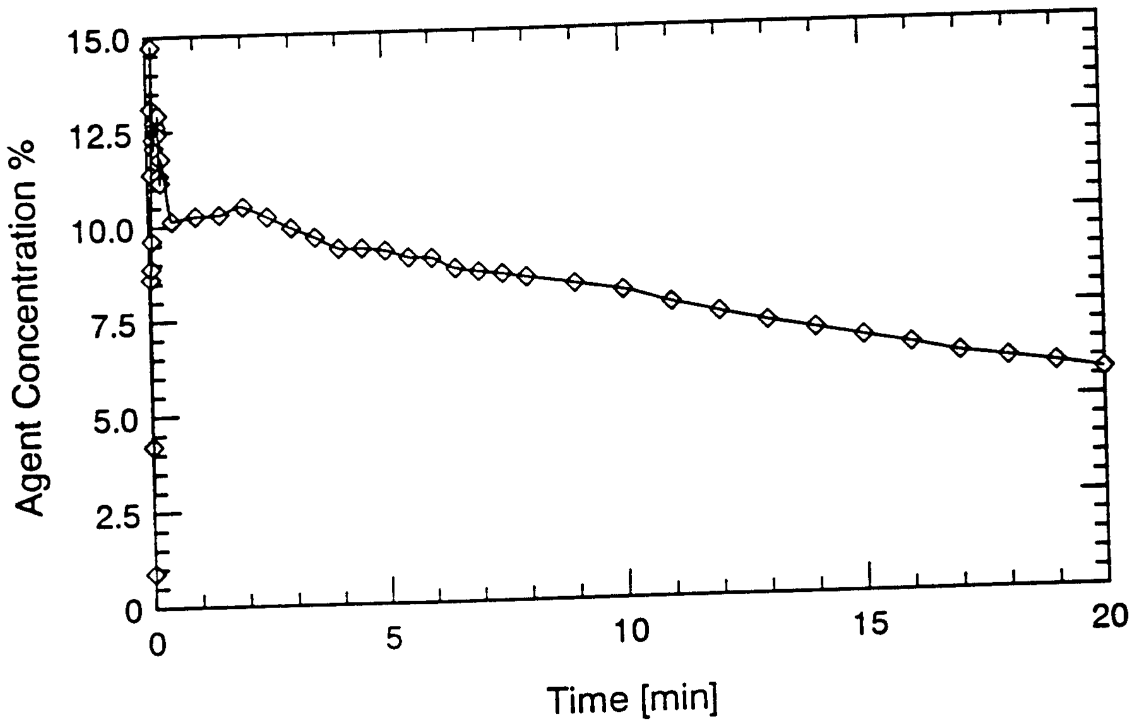



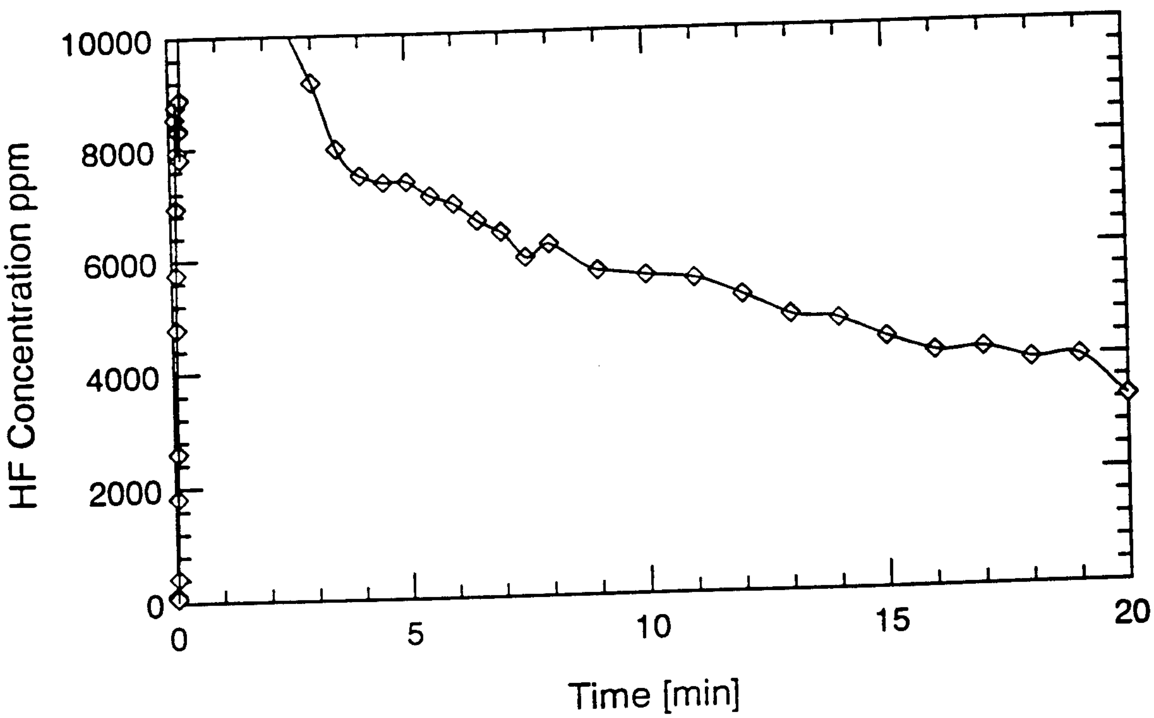

Compartment Temperatures
TEST #21



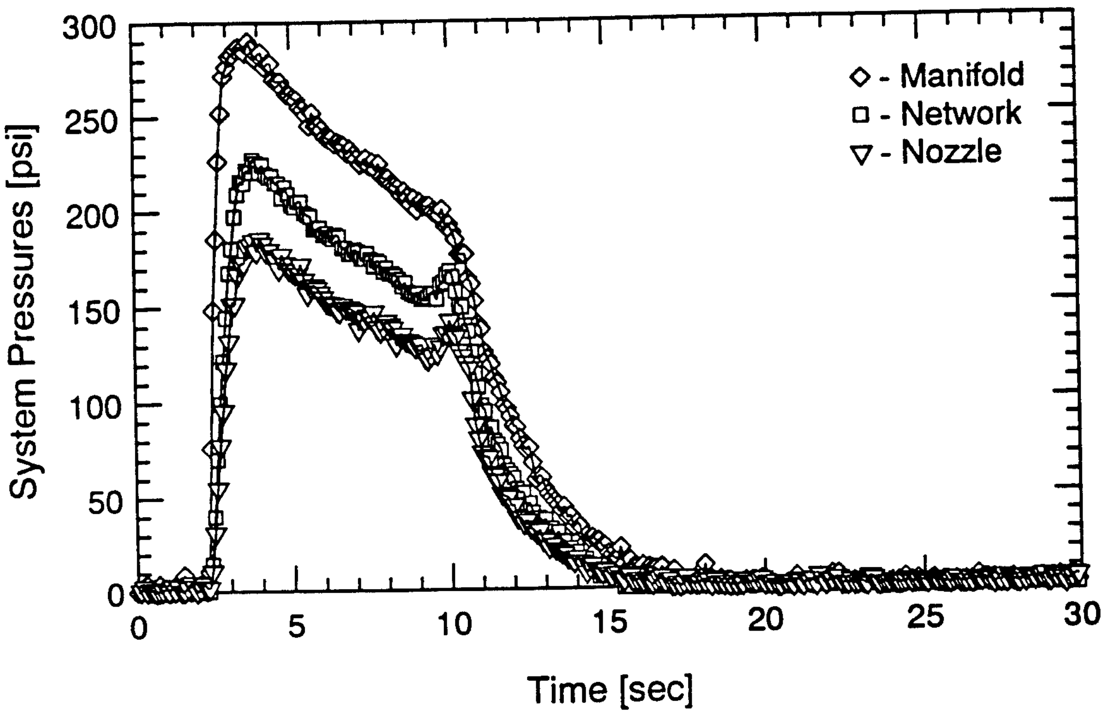



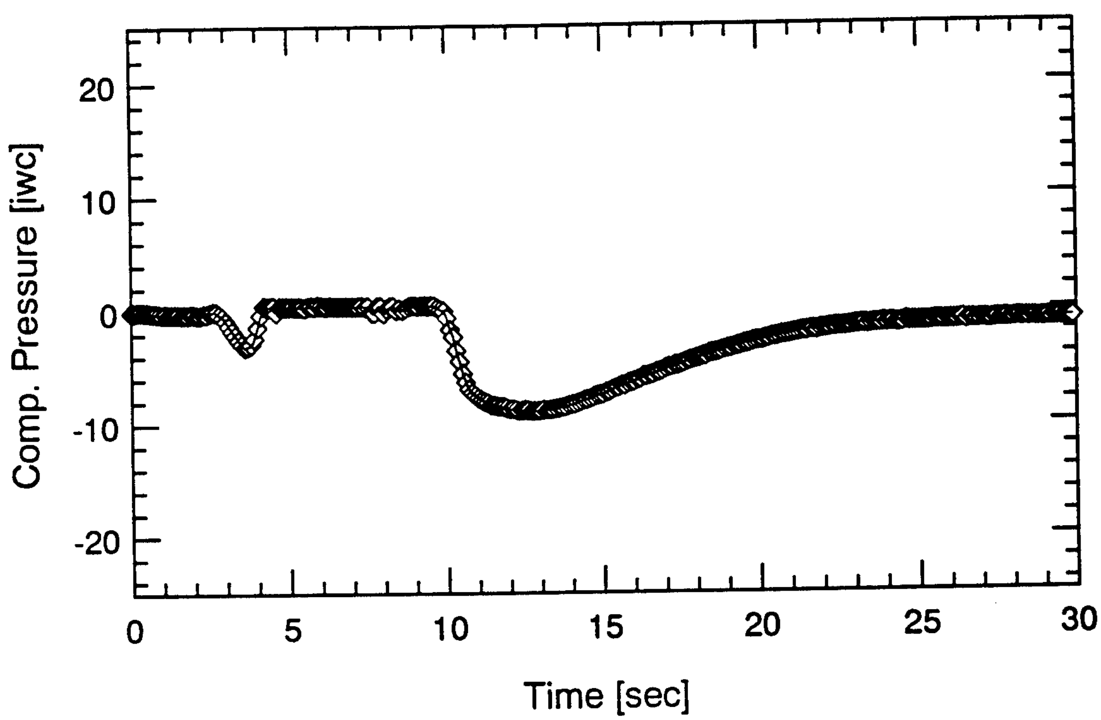

Oxygen Concentrations
TEST #21



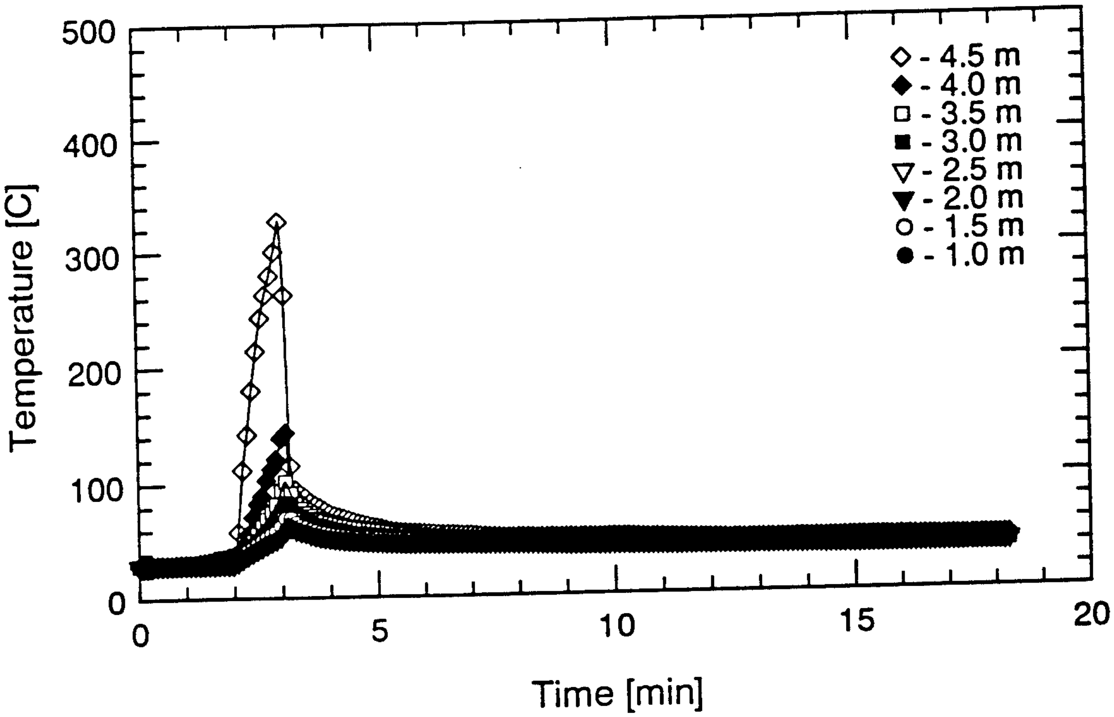



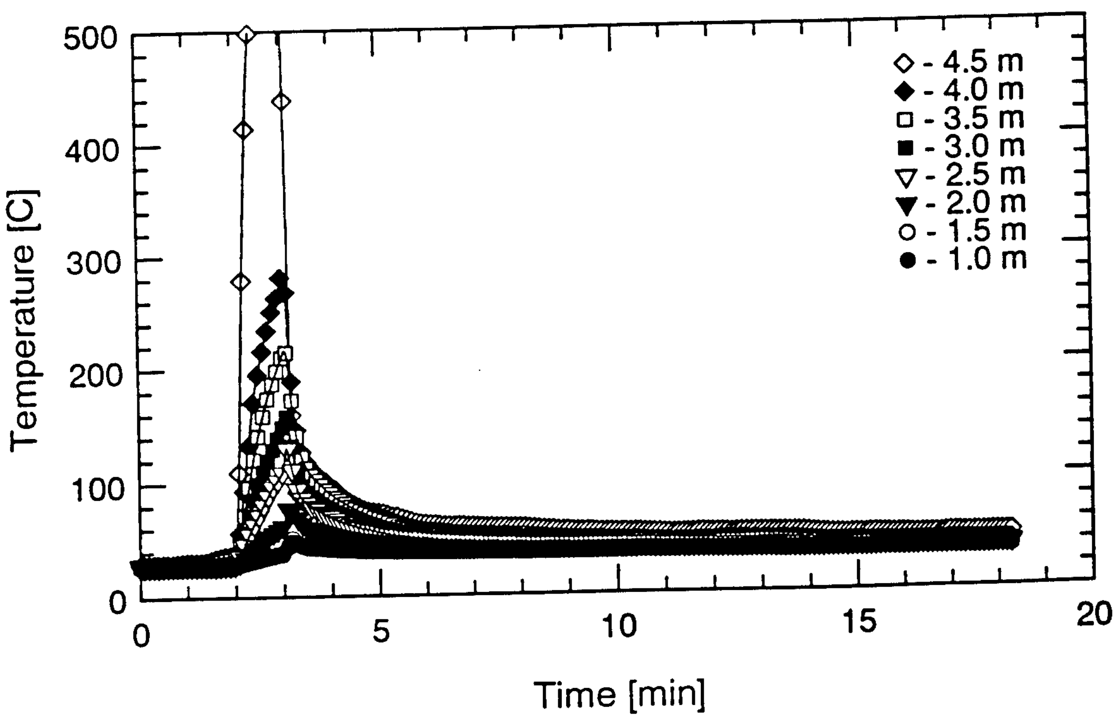

Agent and HF Concentrations
TEST #21



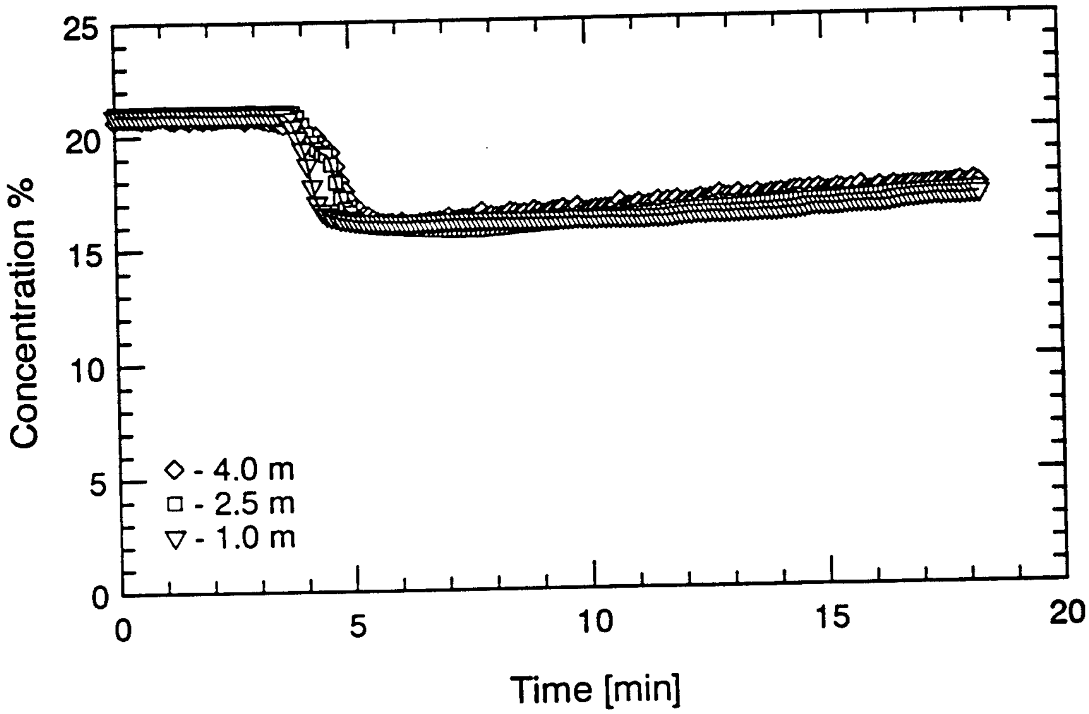



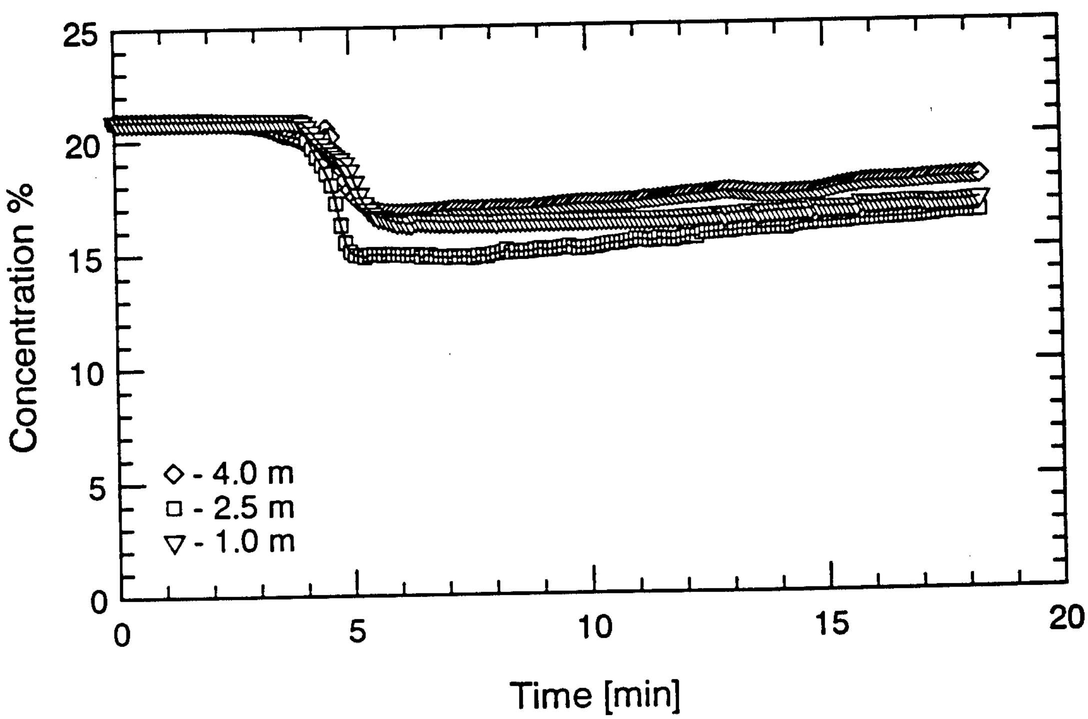

Pressure Measurements
TEST #21



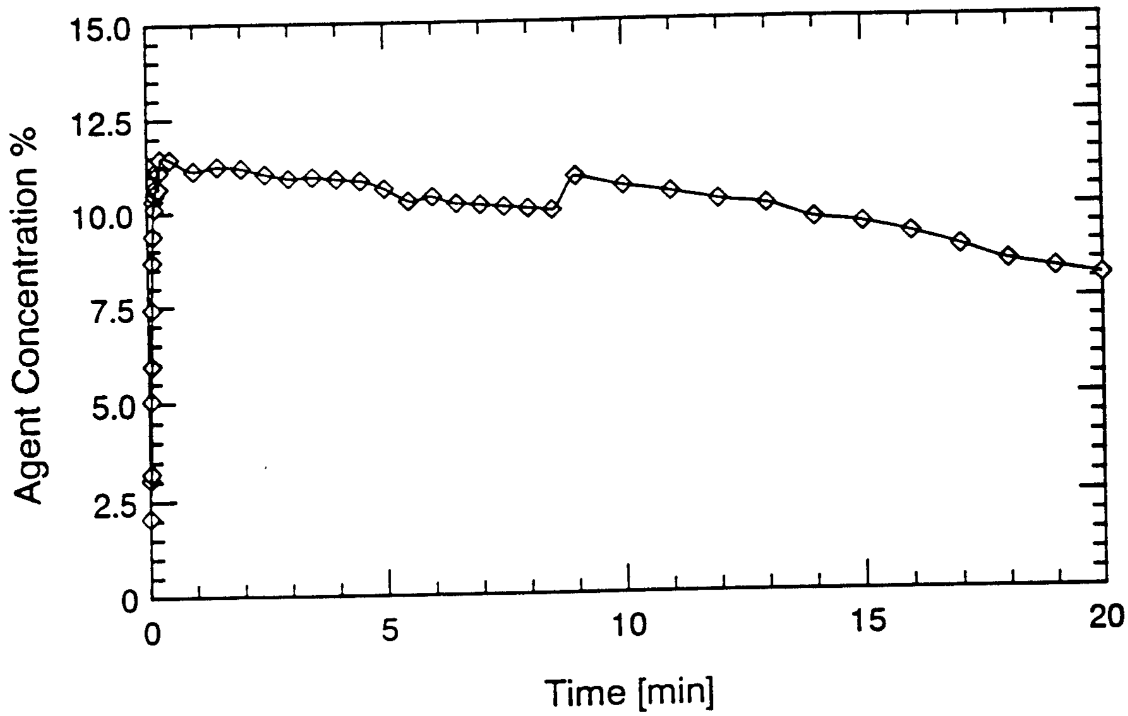



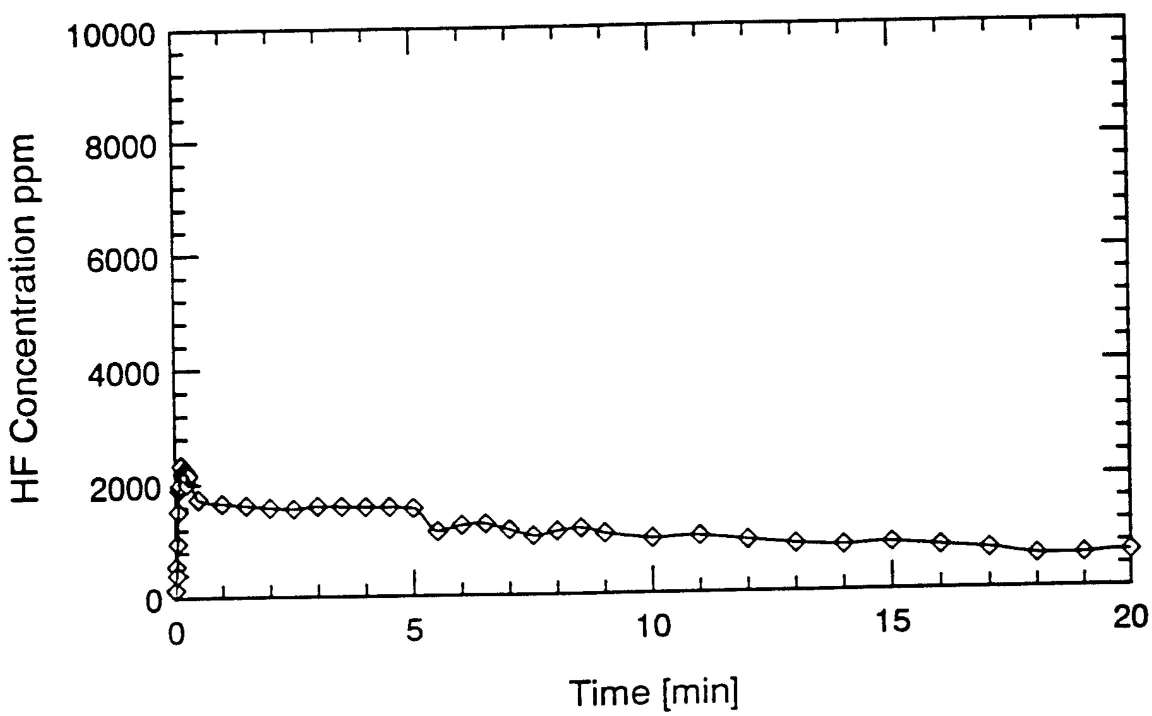

Compartment Temperatures
TEST #22



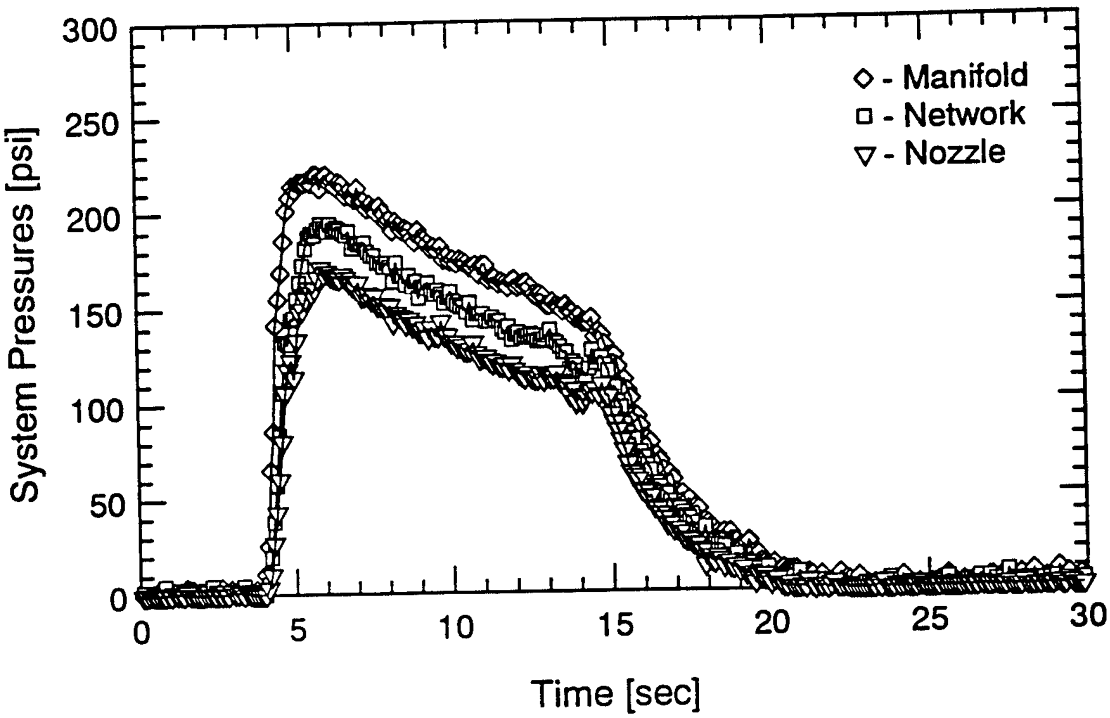



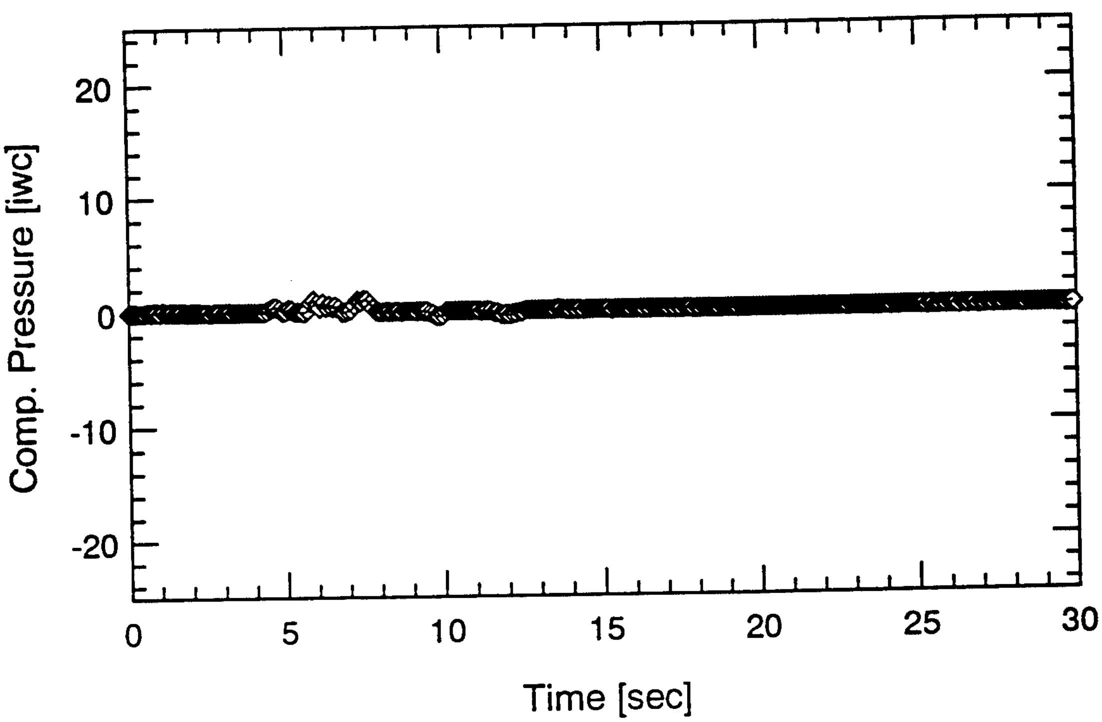

Oxygen Concentrations
TEST #22



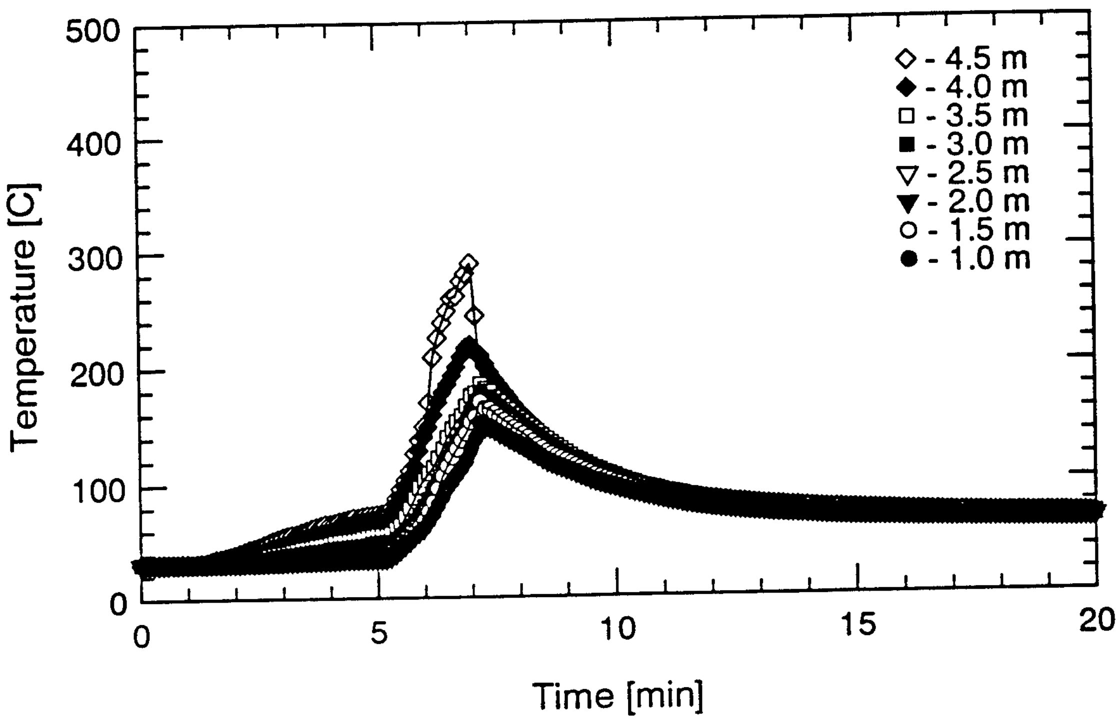



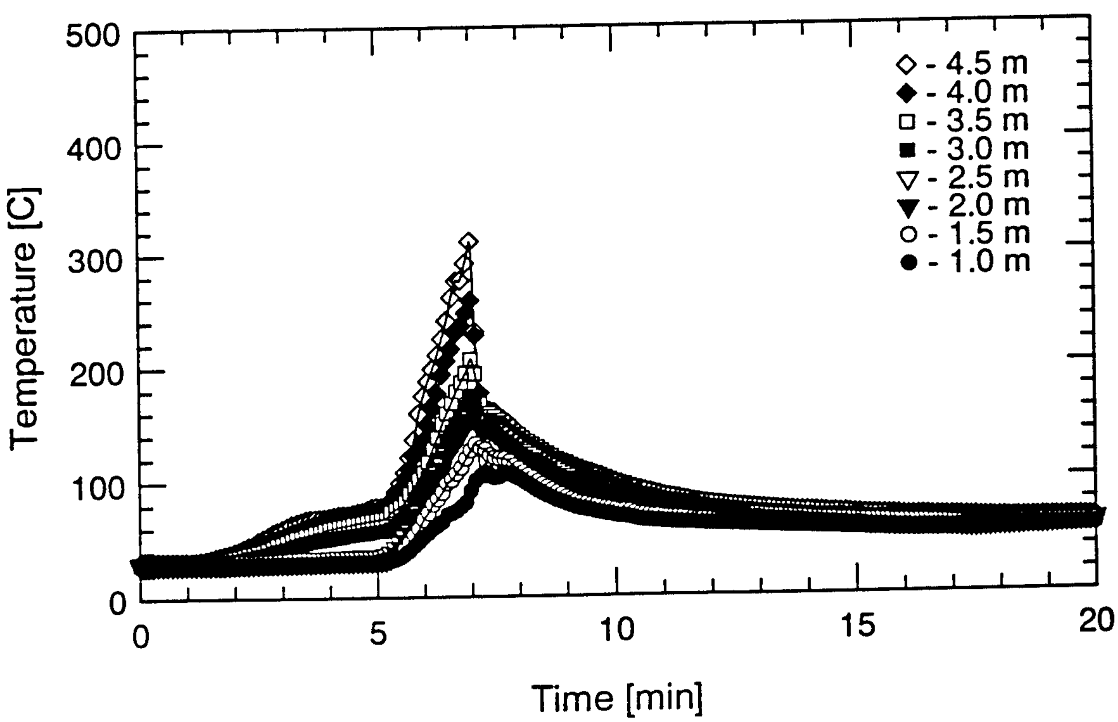

Agent and HF Concentrations
TEST #22



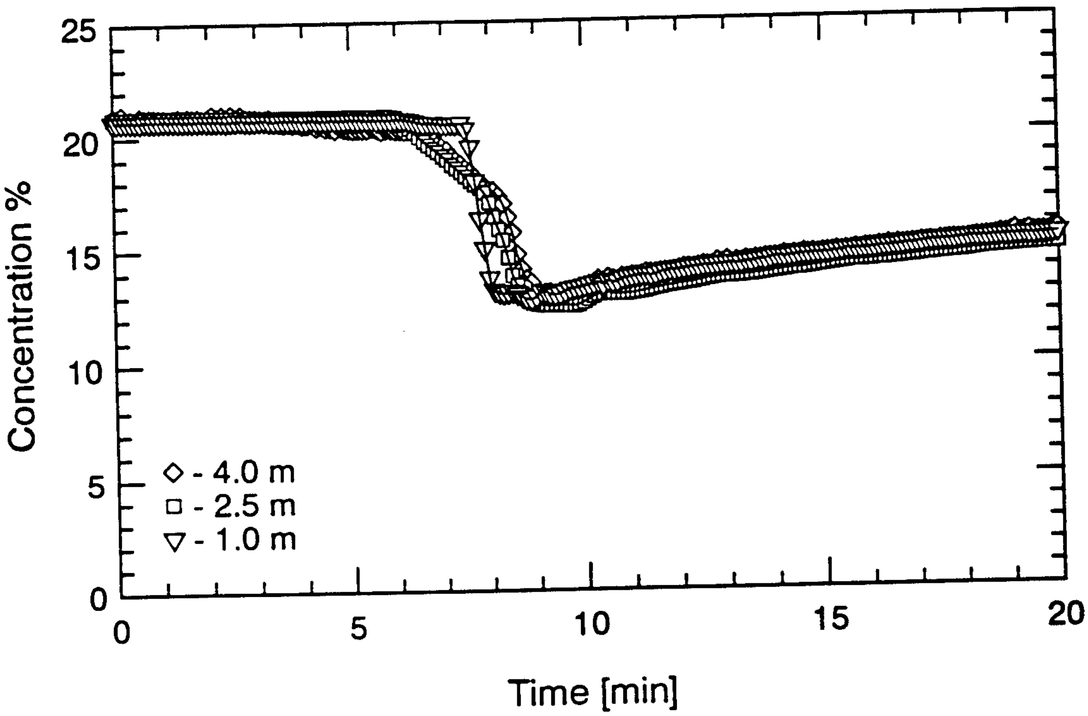



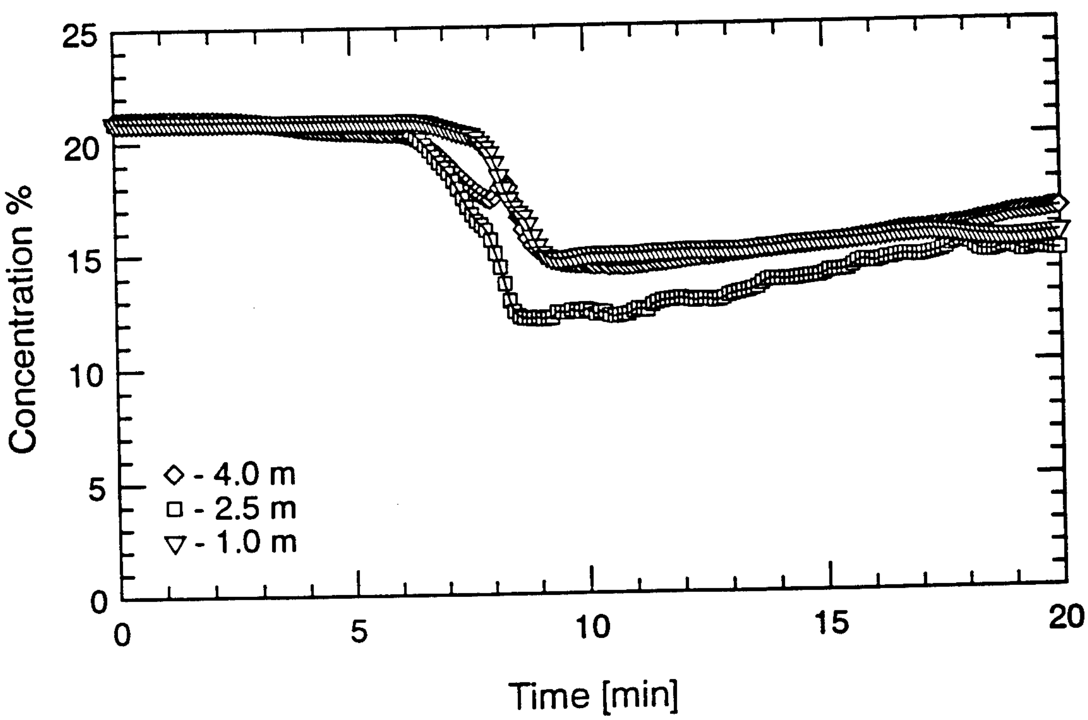

Pressure Measurements
TEST #22



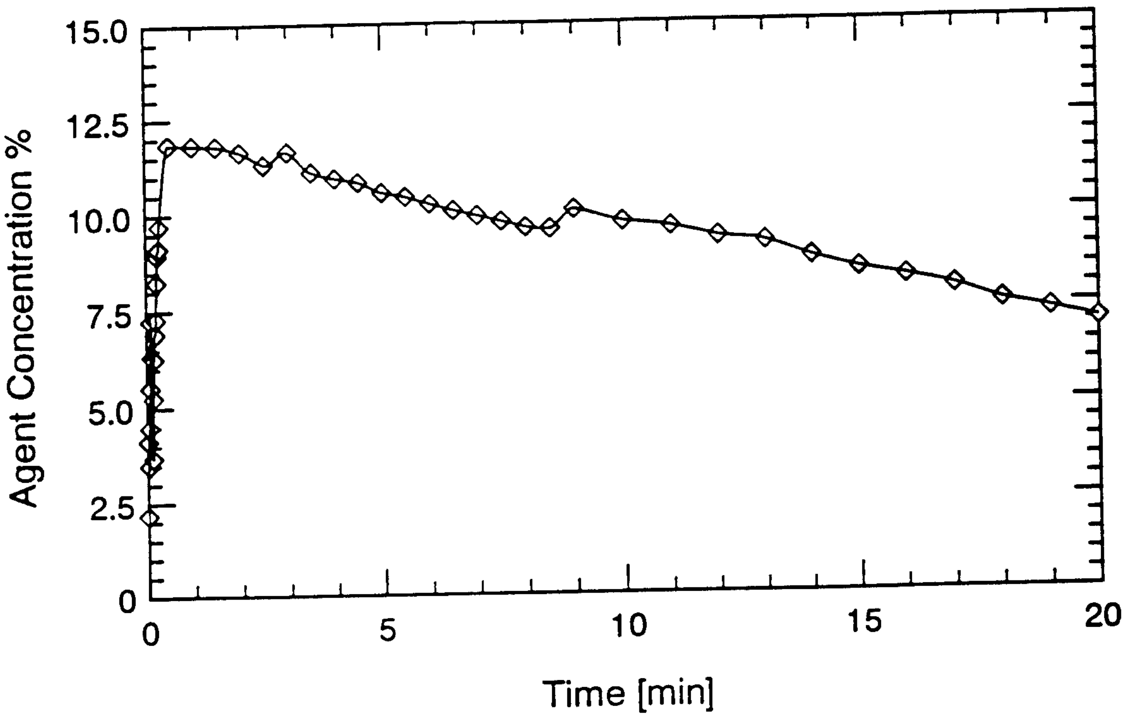



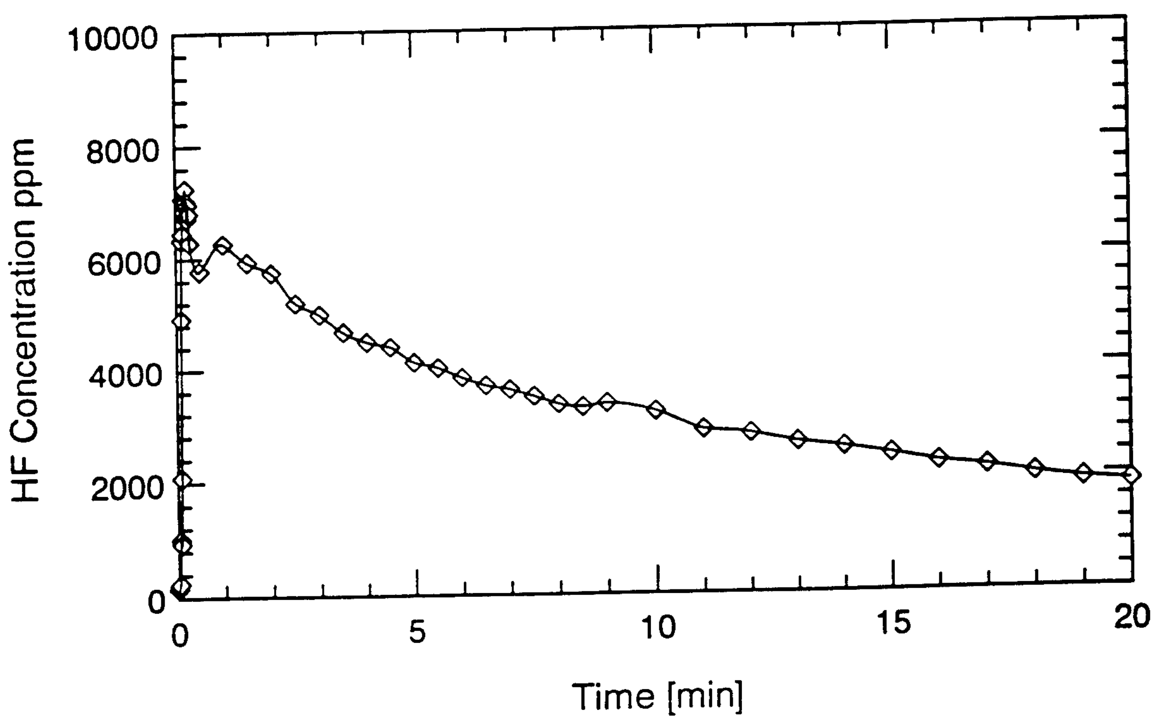

Compartment Temperatures
TEST #23



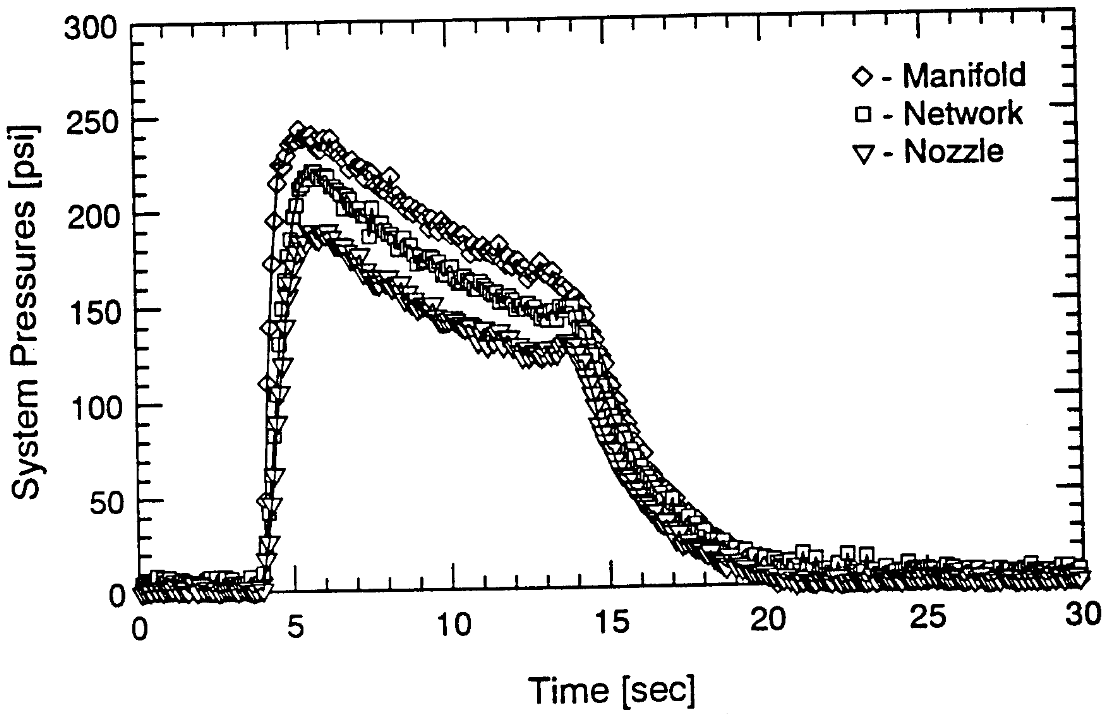



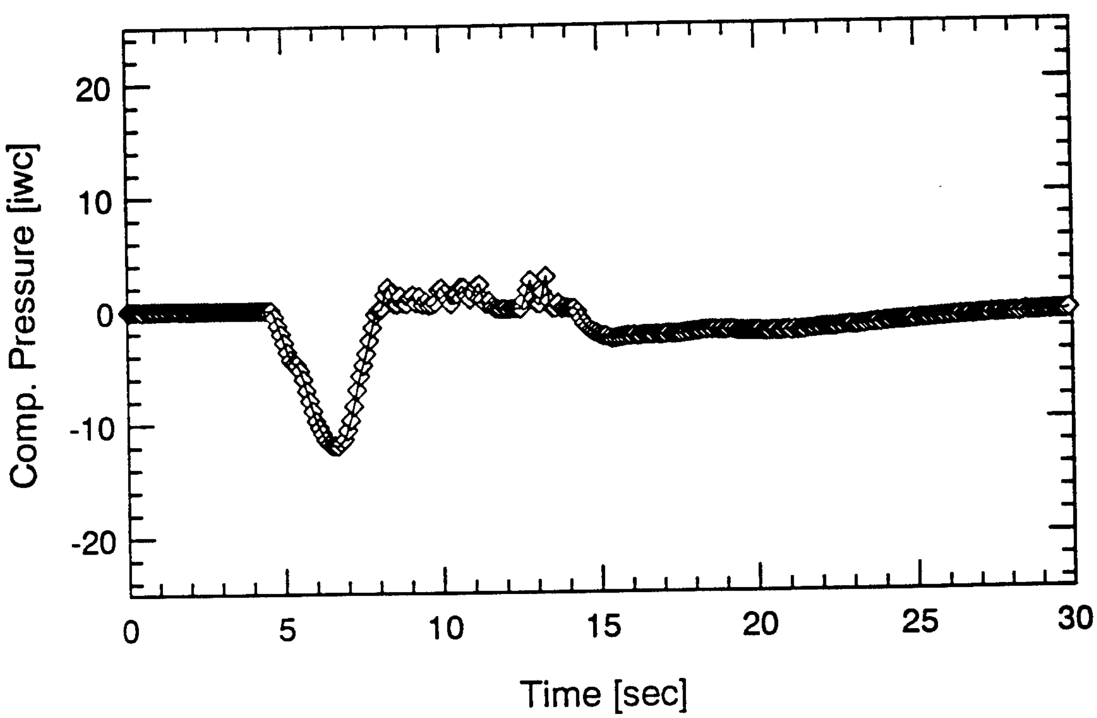

Oxygen Concentrations
TEST #23



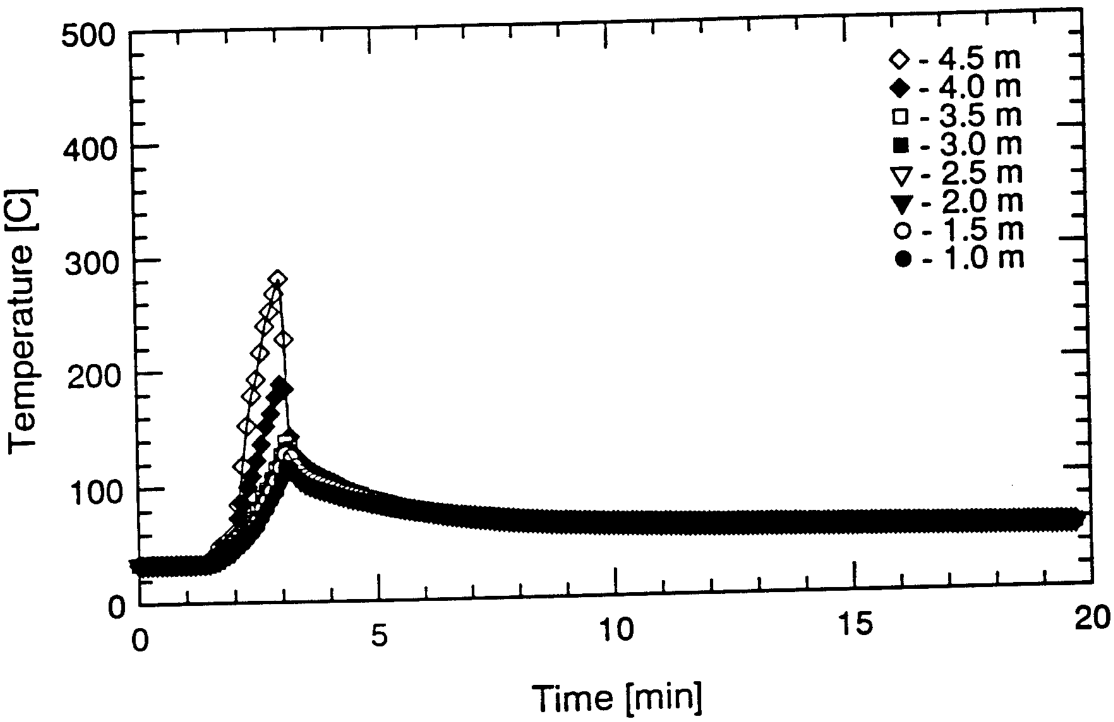



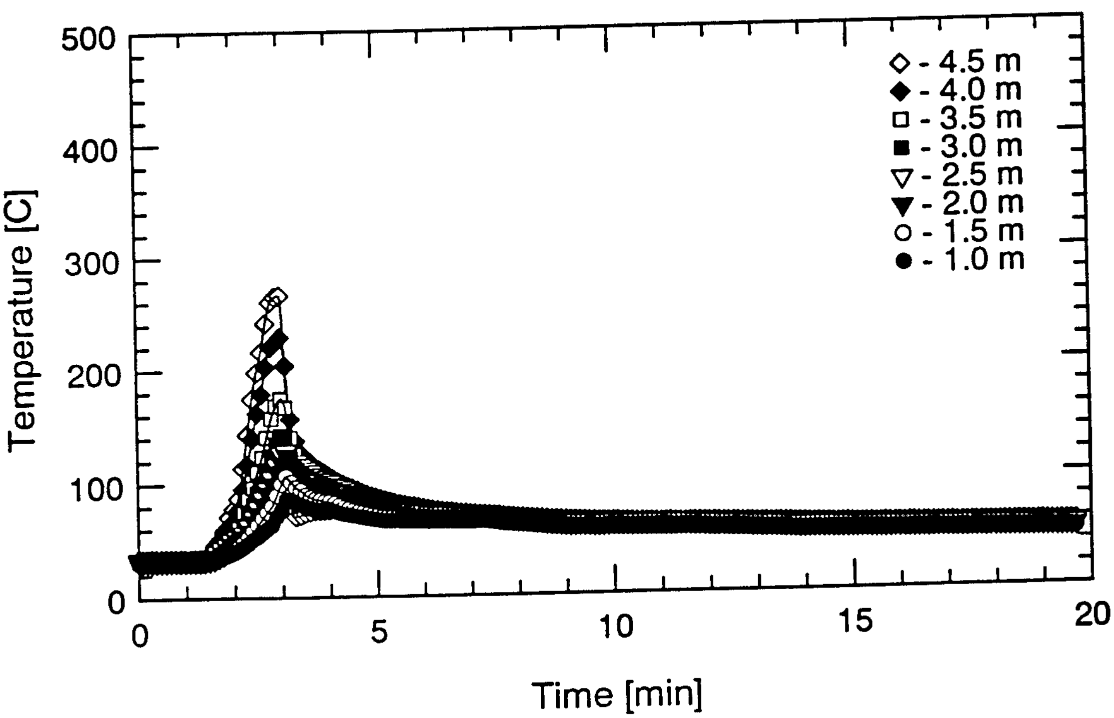

Agent and HF Concentrations
TEST #23



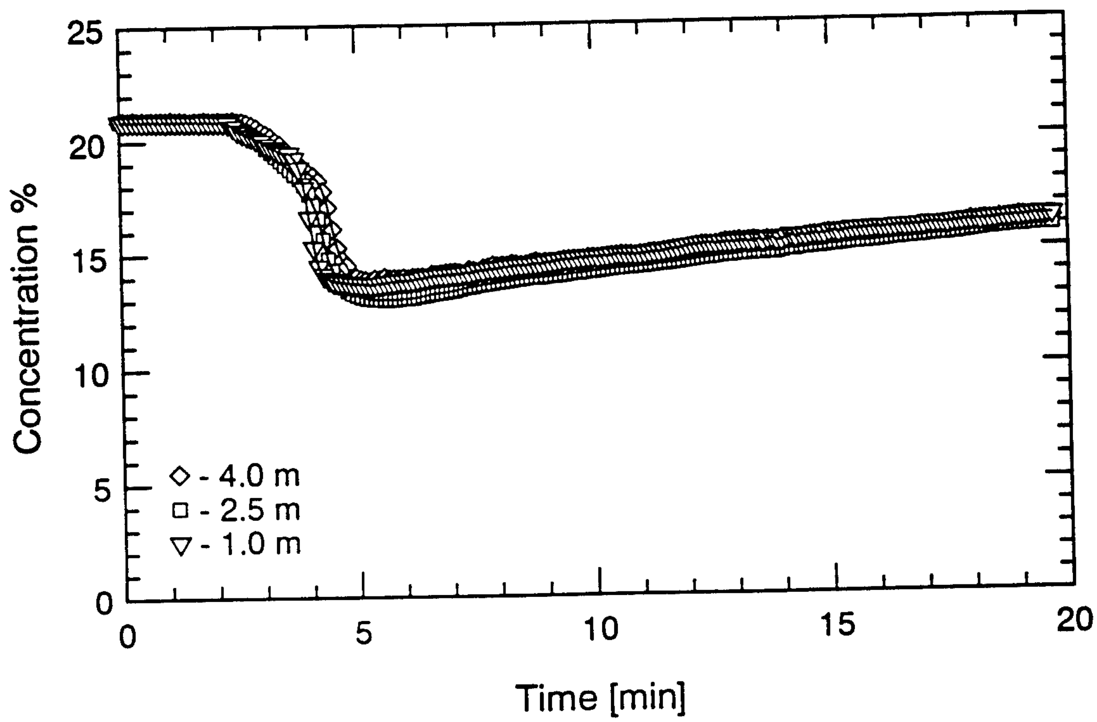



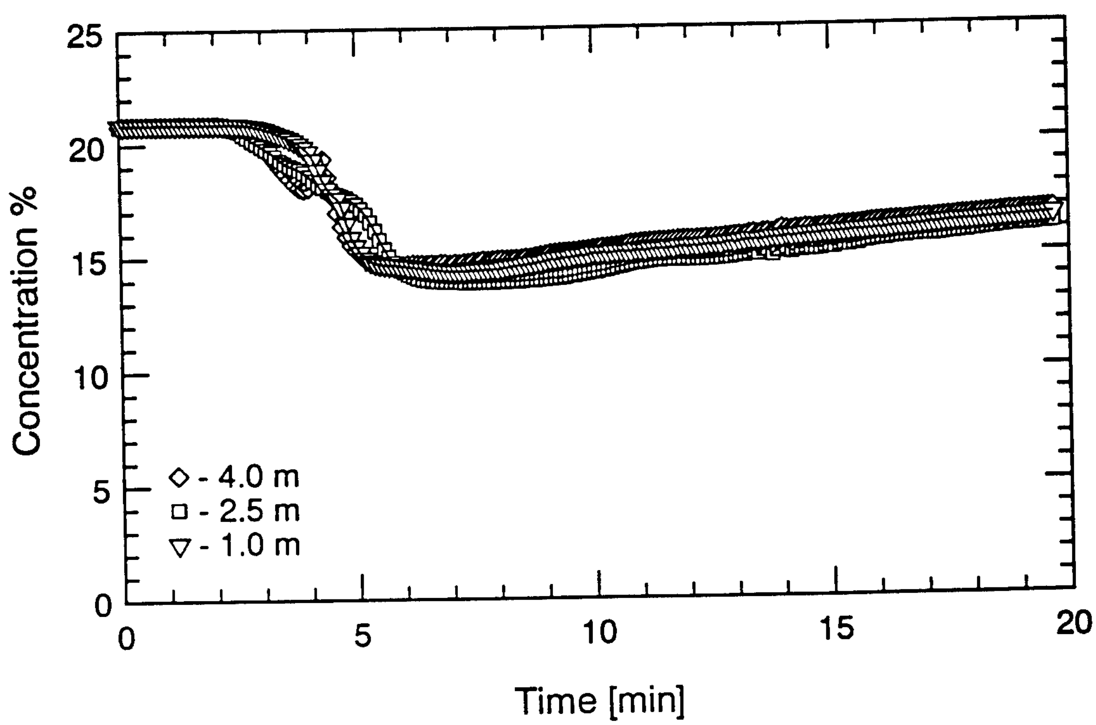

Pressure Measurements
TEST #23



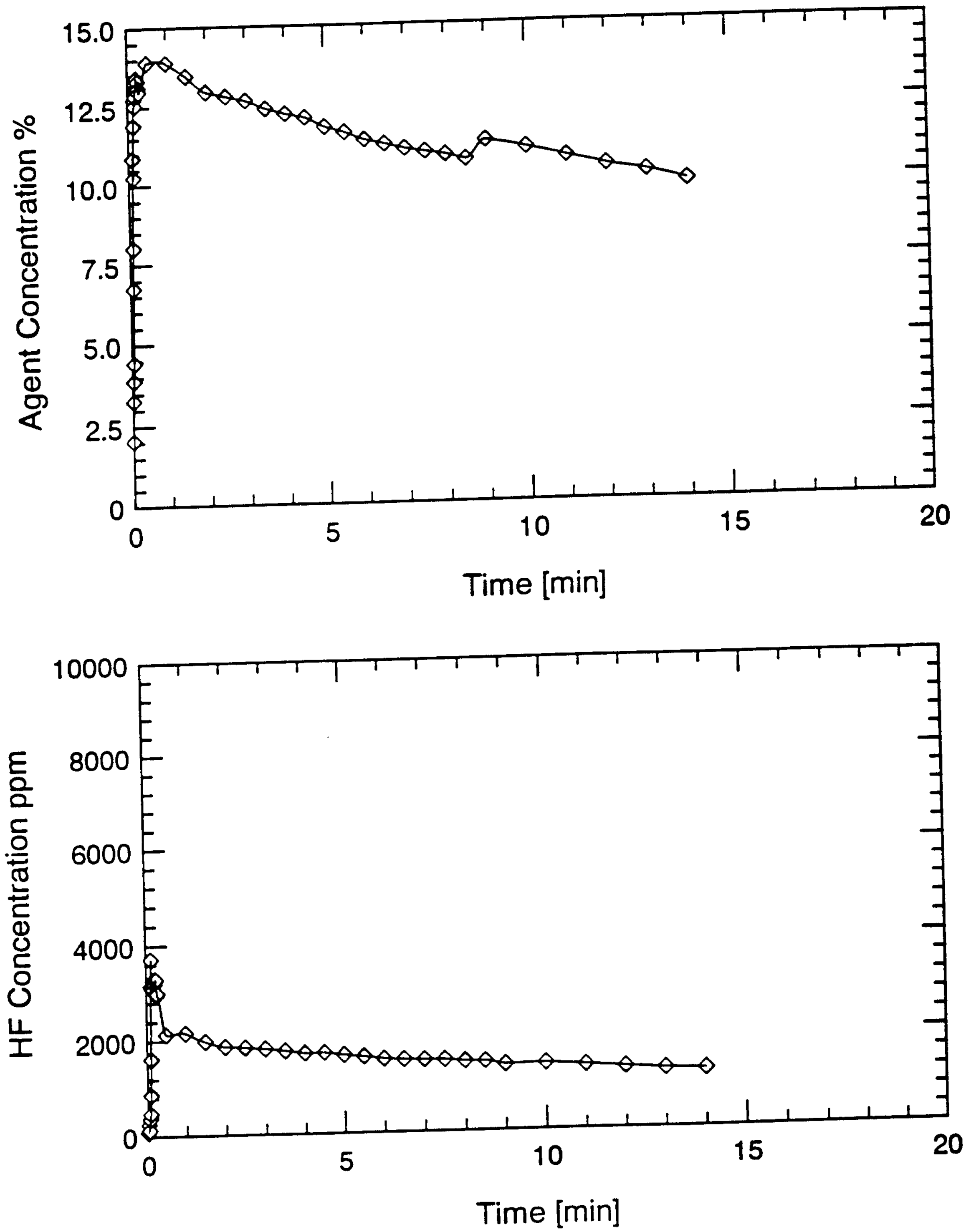




Compartment Temperatures
TEST #24

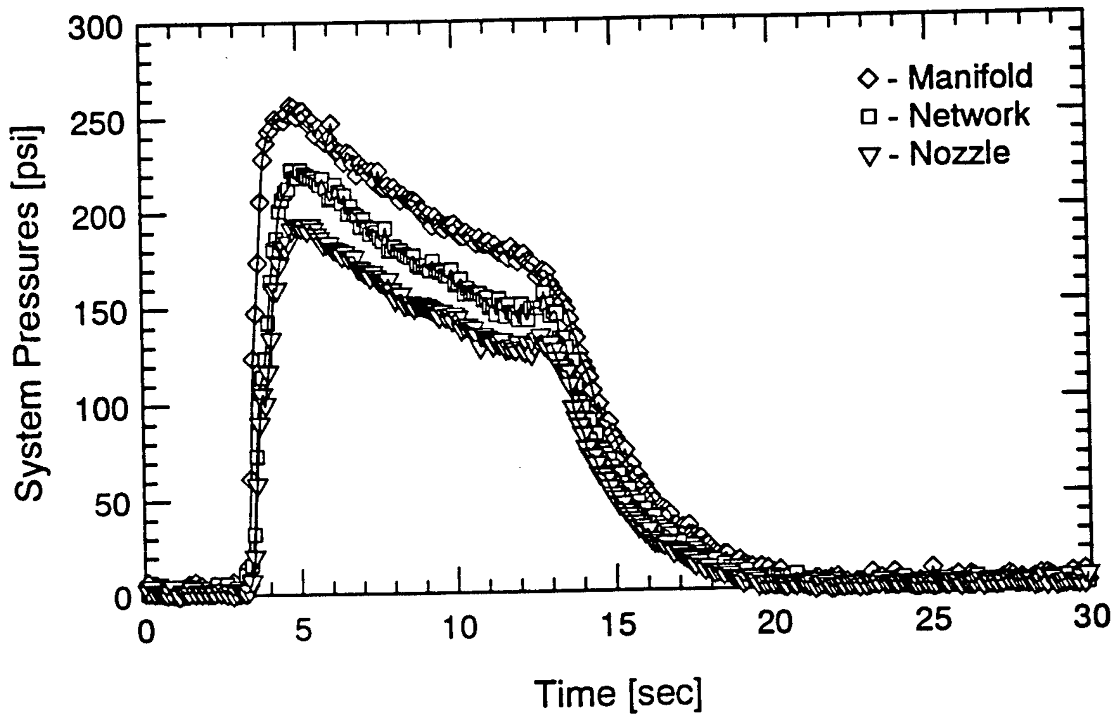


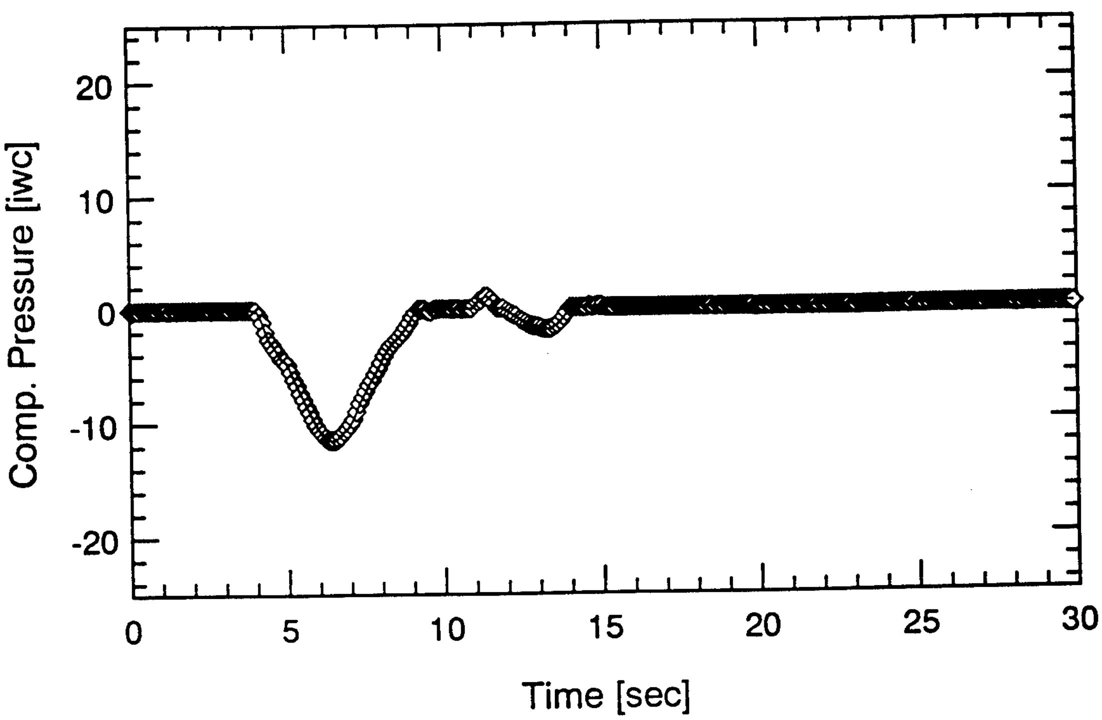




Oxygen Concentrations
TEST #24

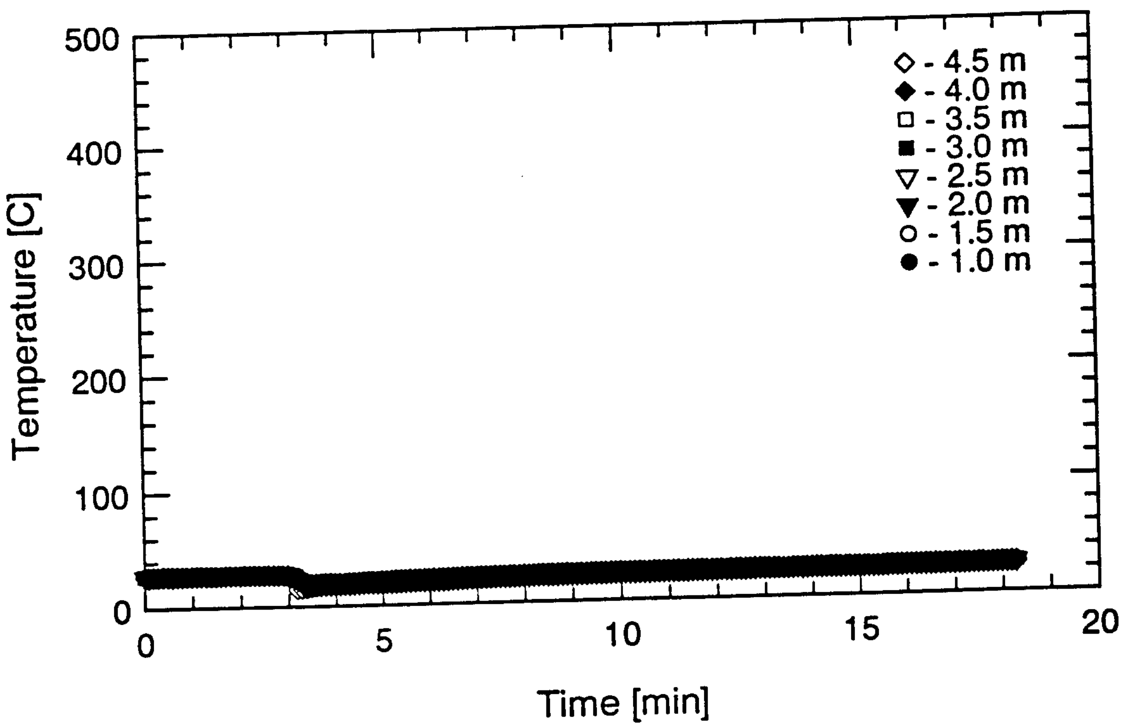


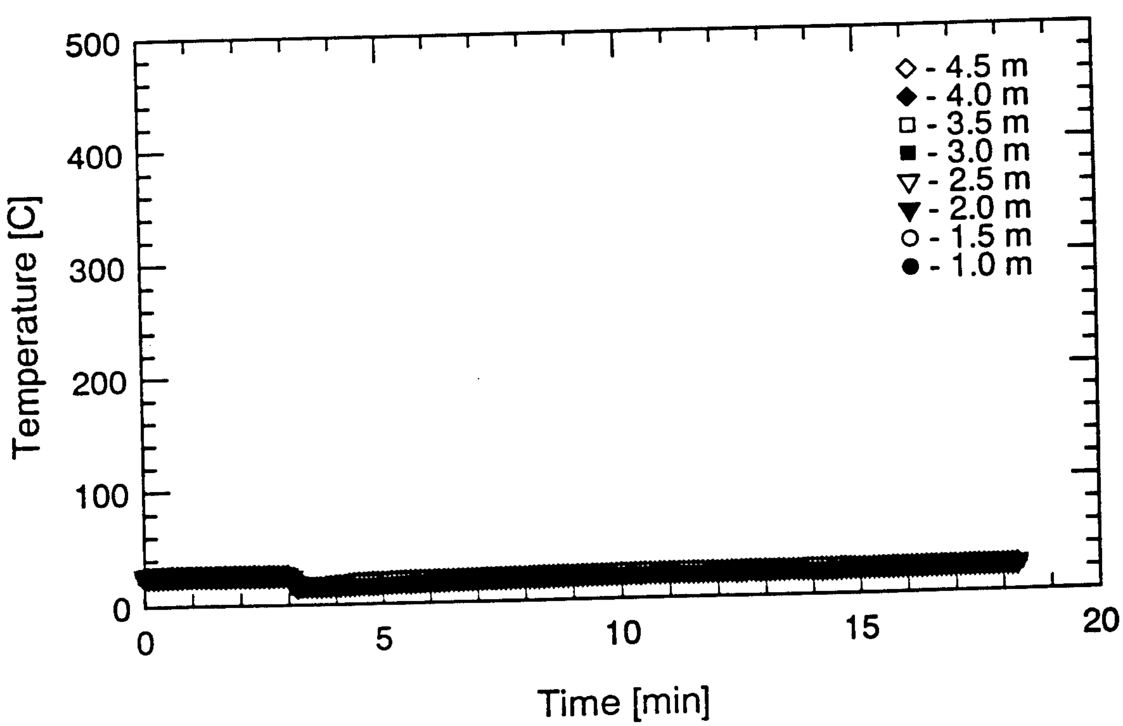

Agent and HF Concentrations
TEST #24



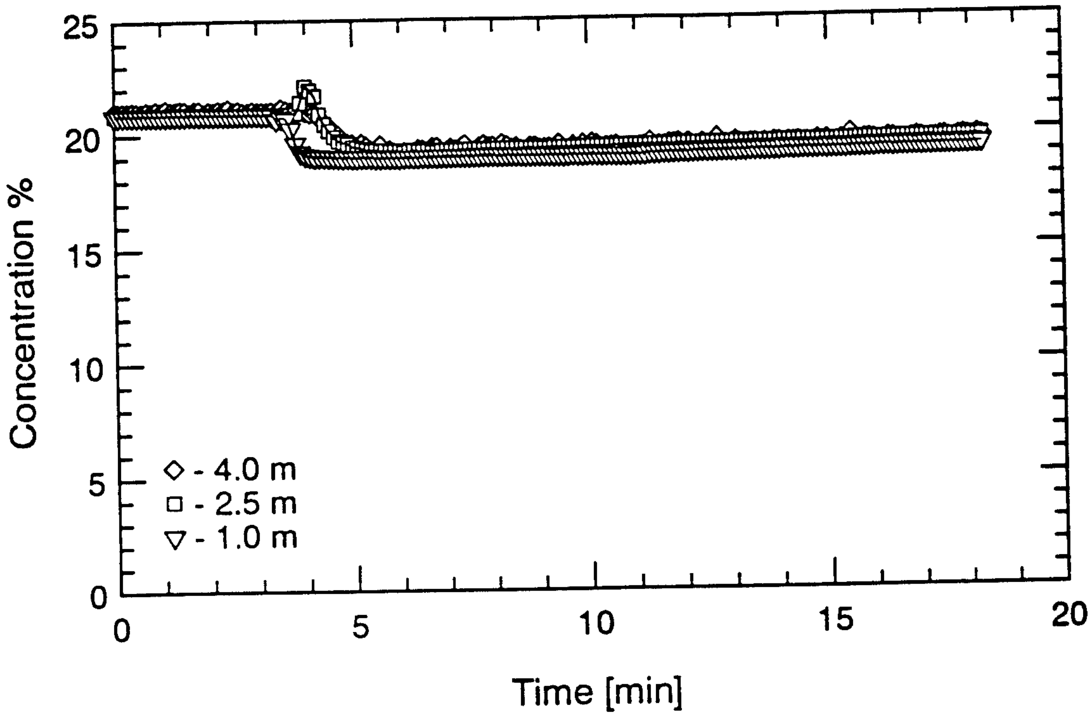



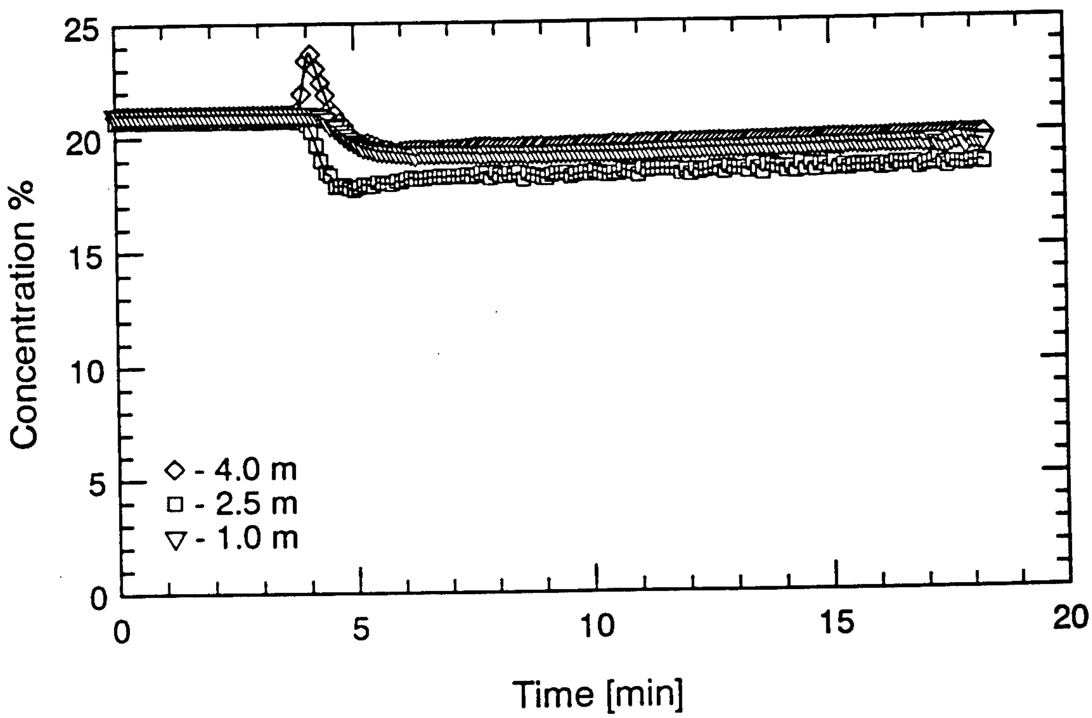

Pressure Measurements
TEST #24



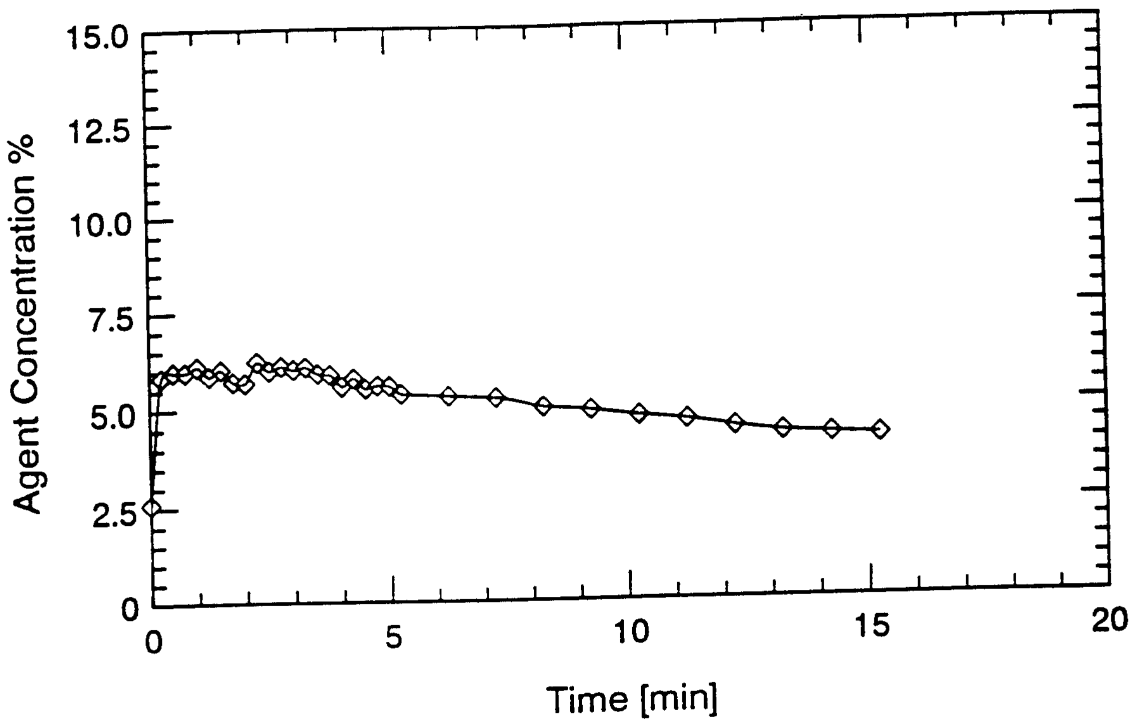



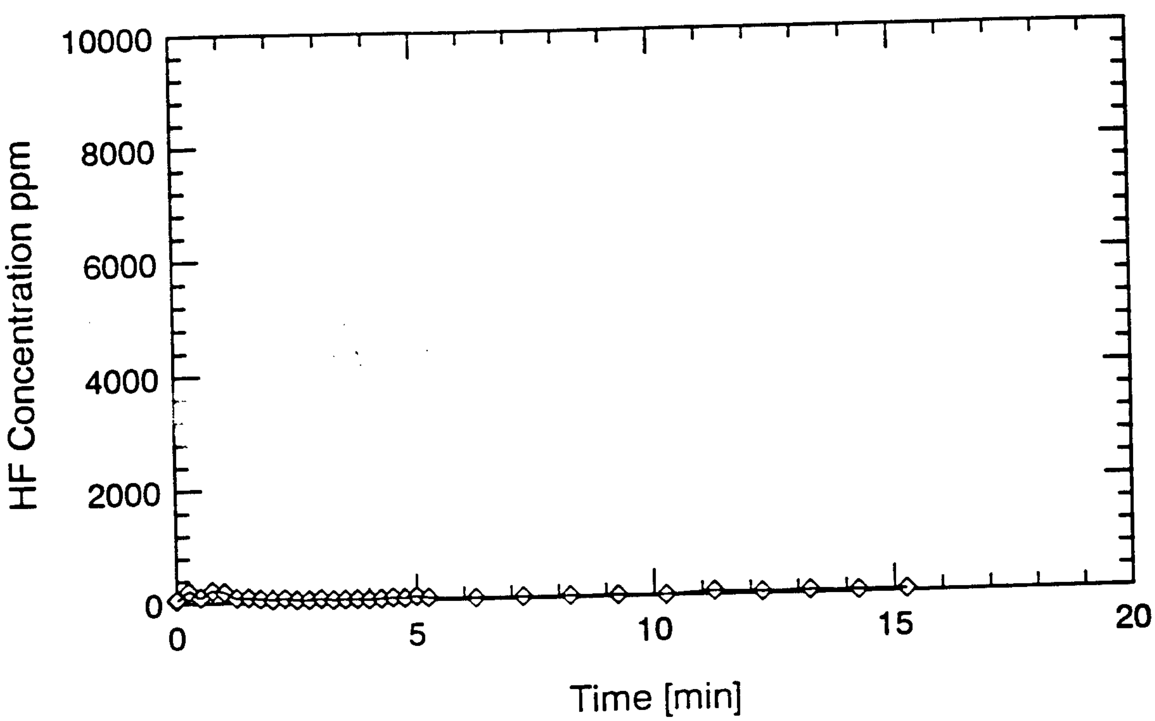

Compartment Temperatures
TEST #25



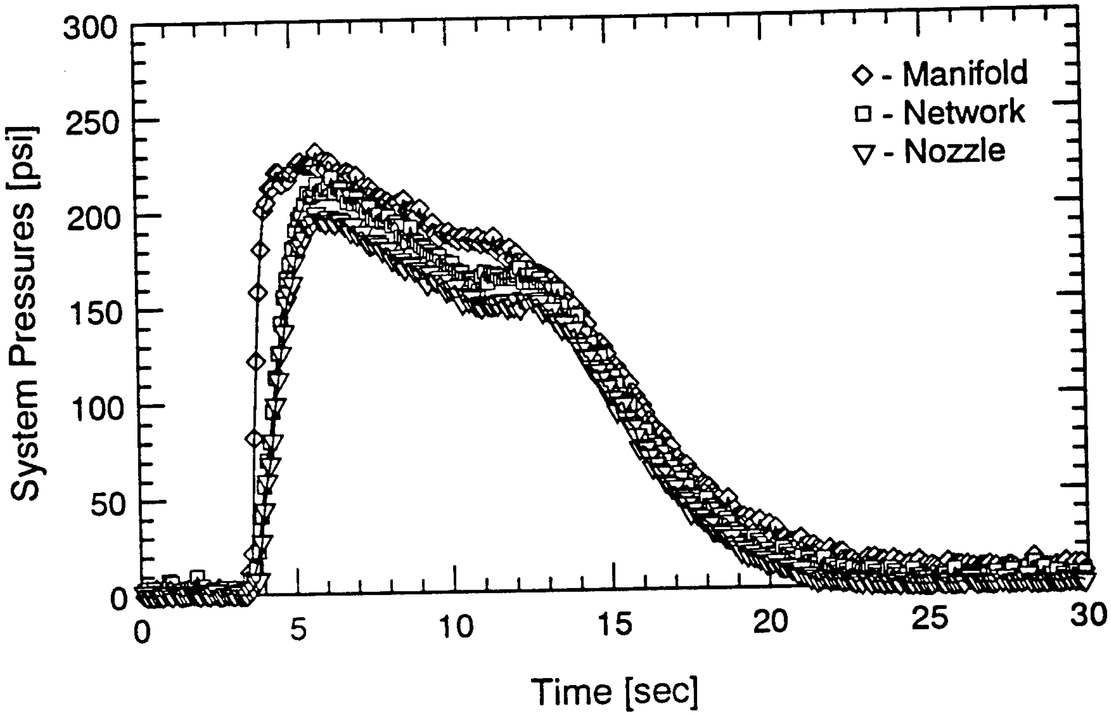



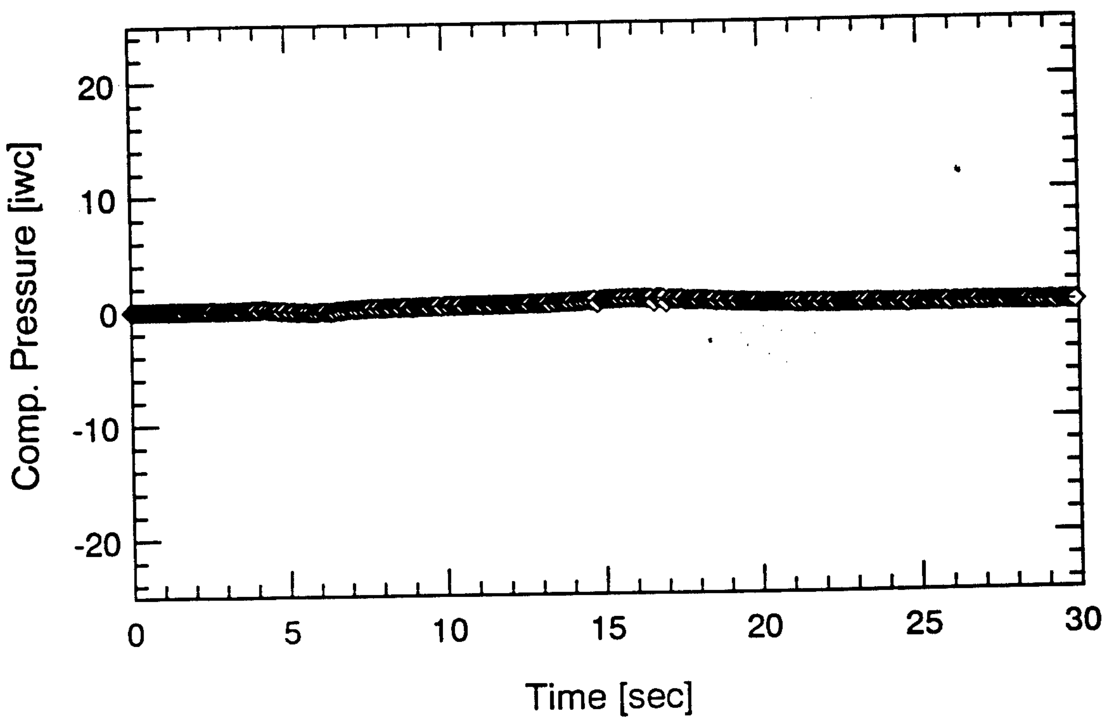

Oxygen Concentrations
TEST #25



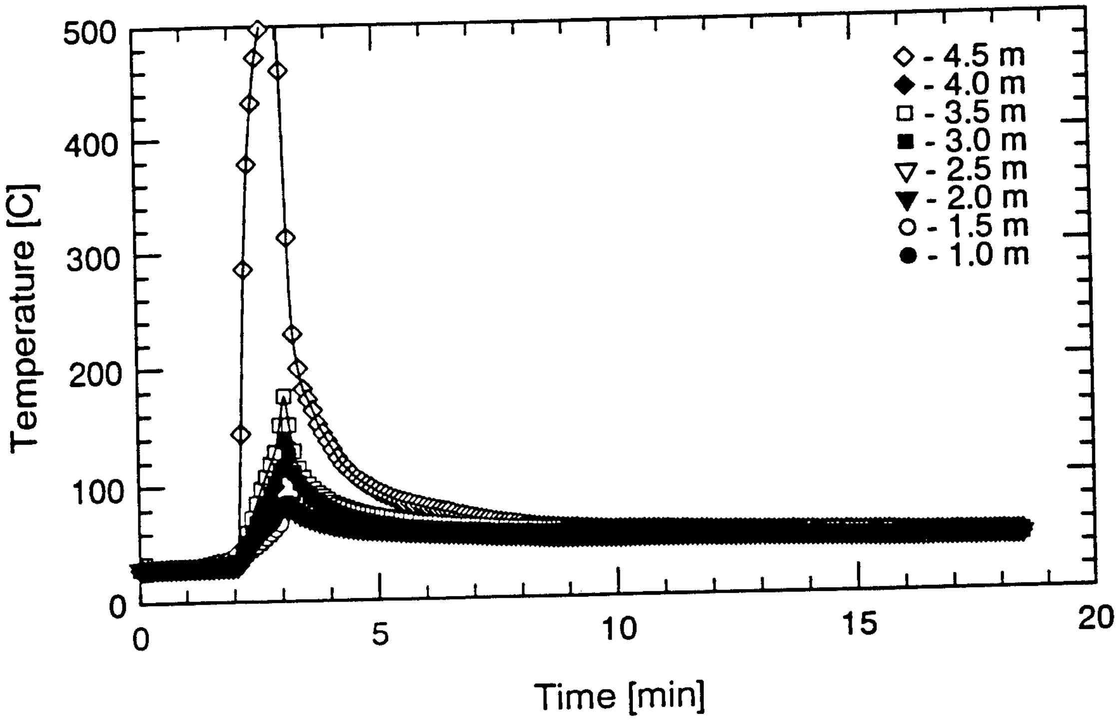



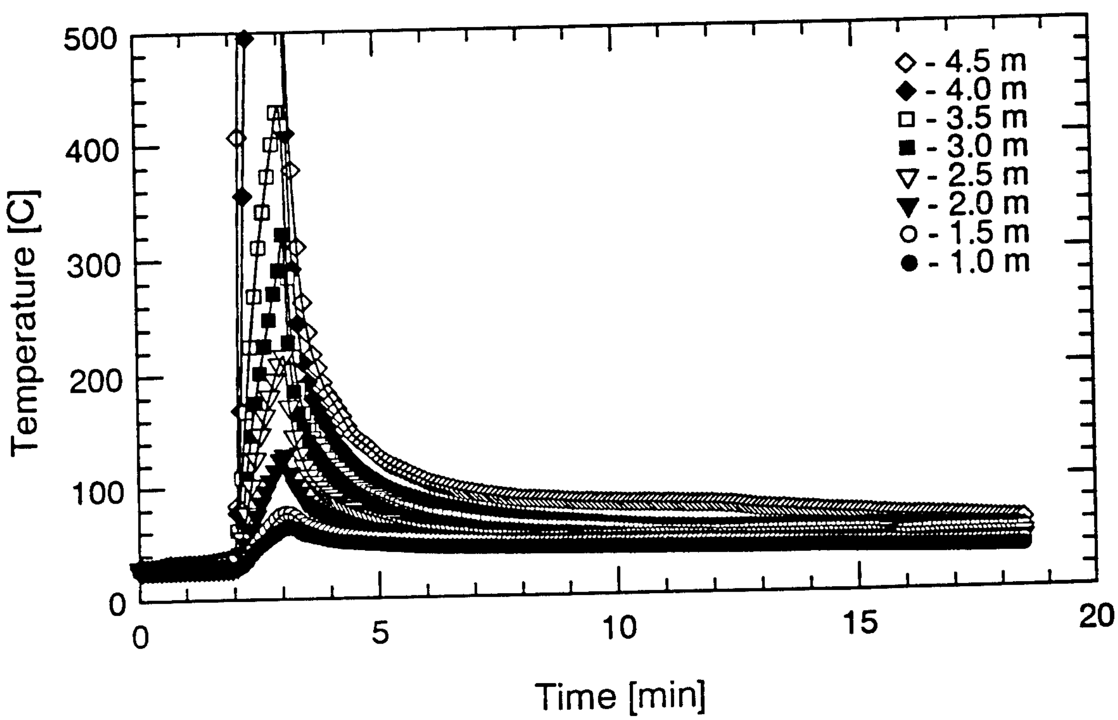

Agent and HF Concentrations
TEST #25



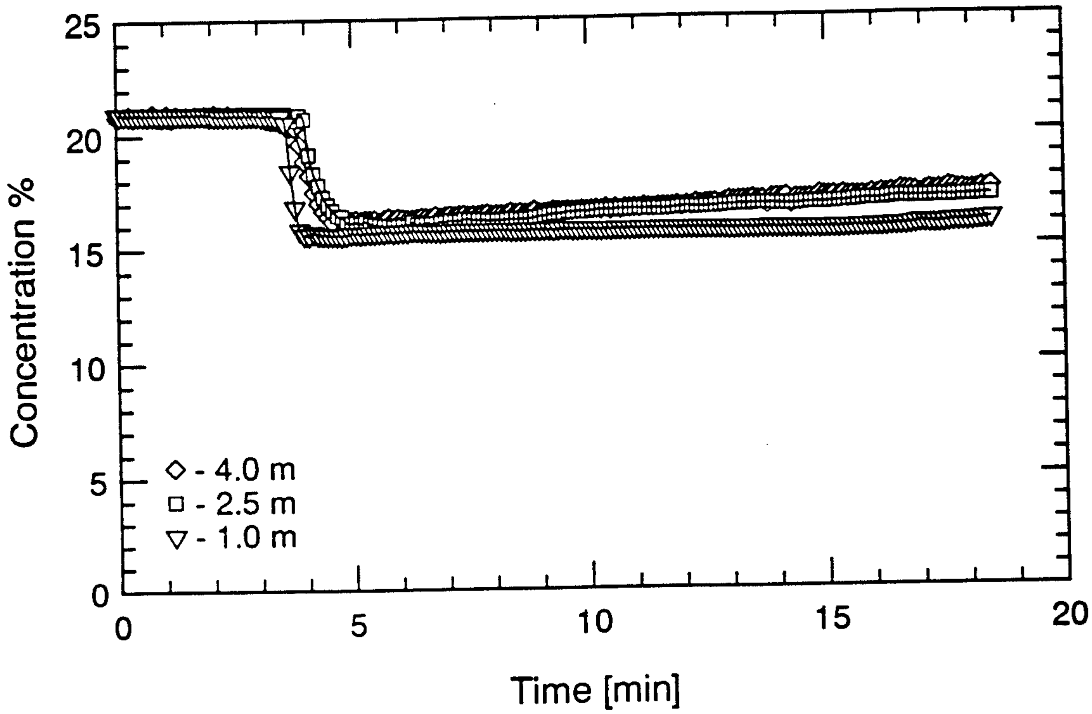



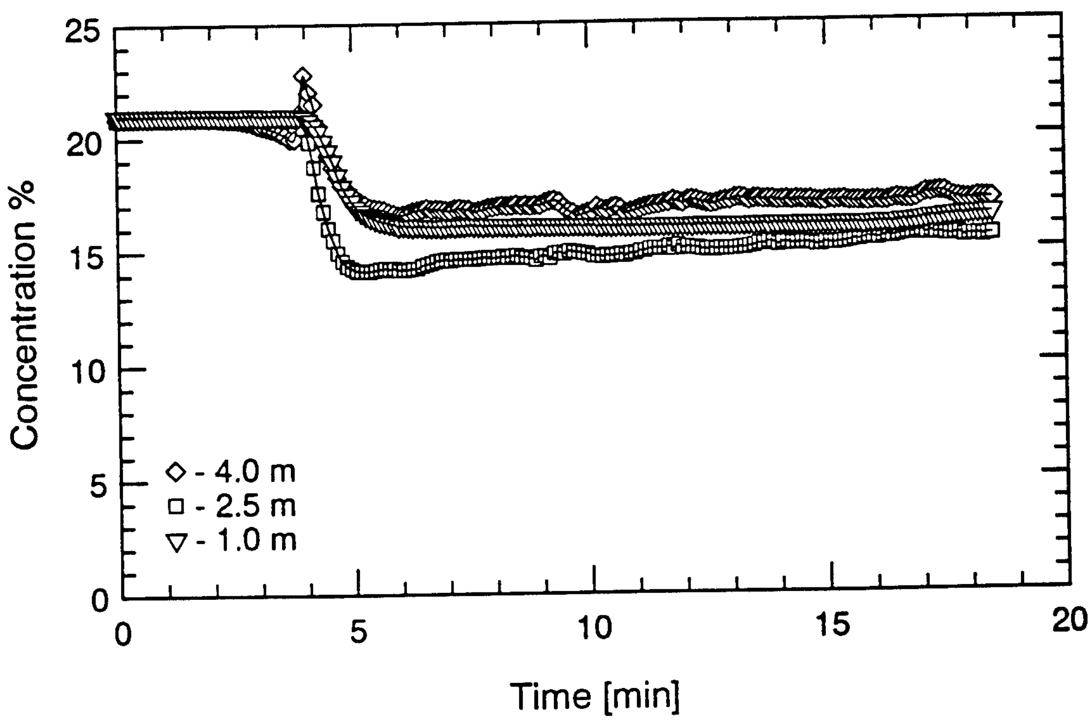

Pressure Measurements
TEST #25



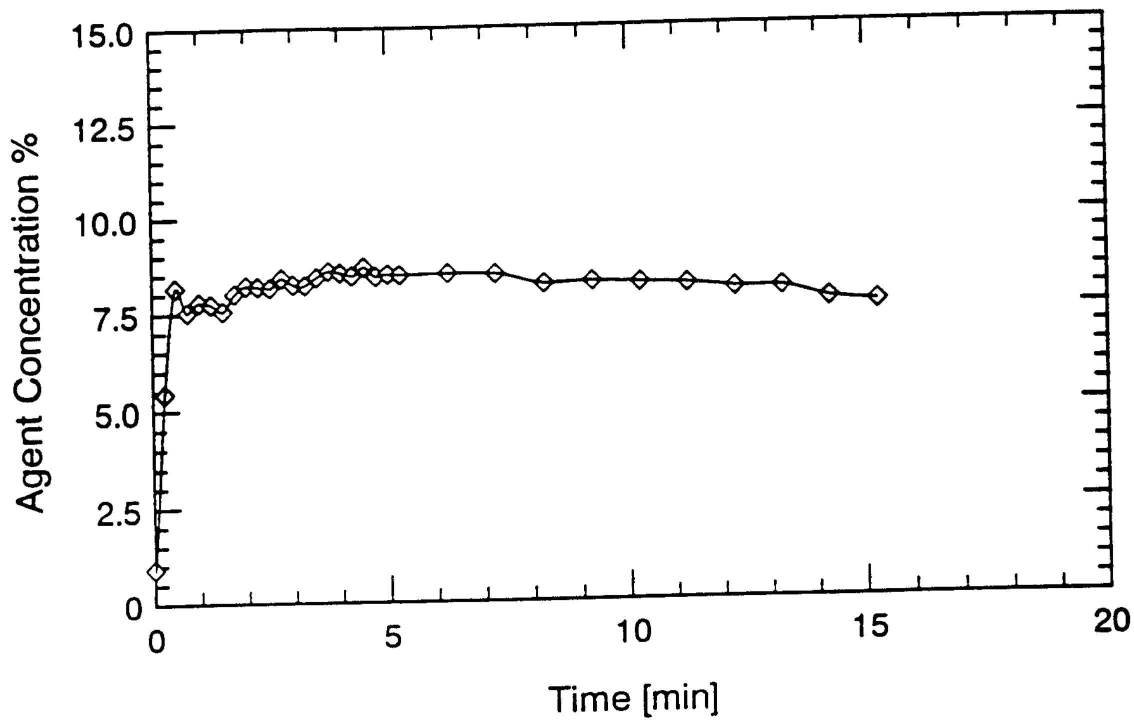



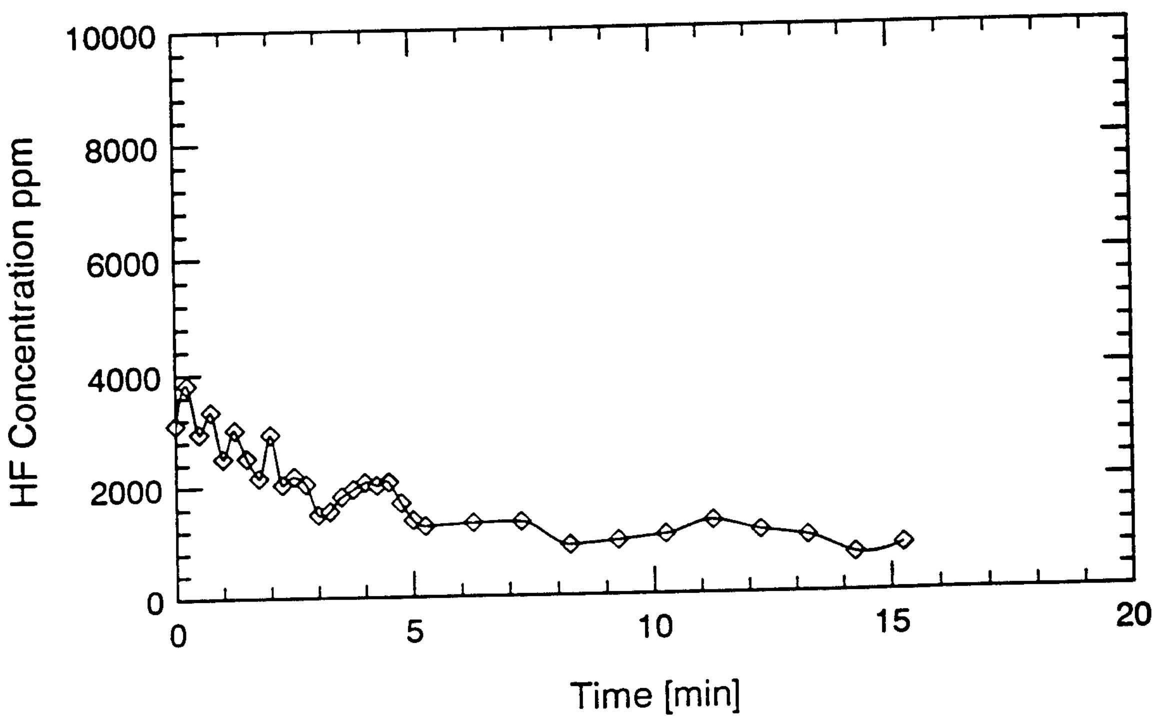

Compartment Temperatures
TEST #26



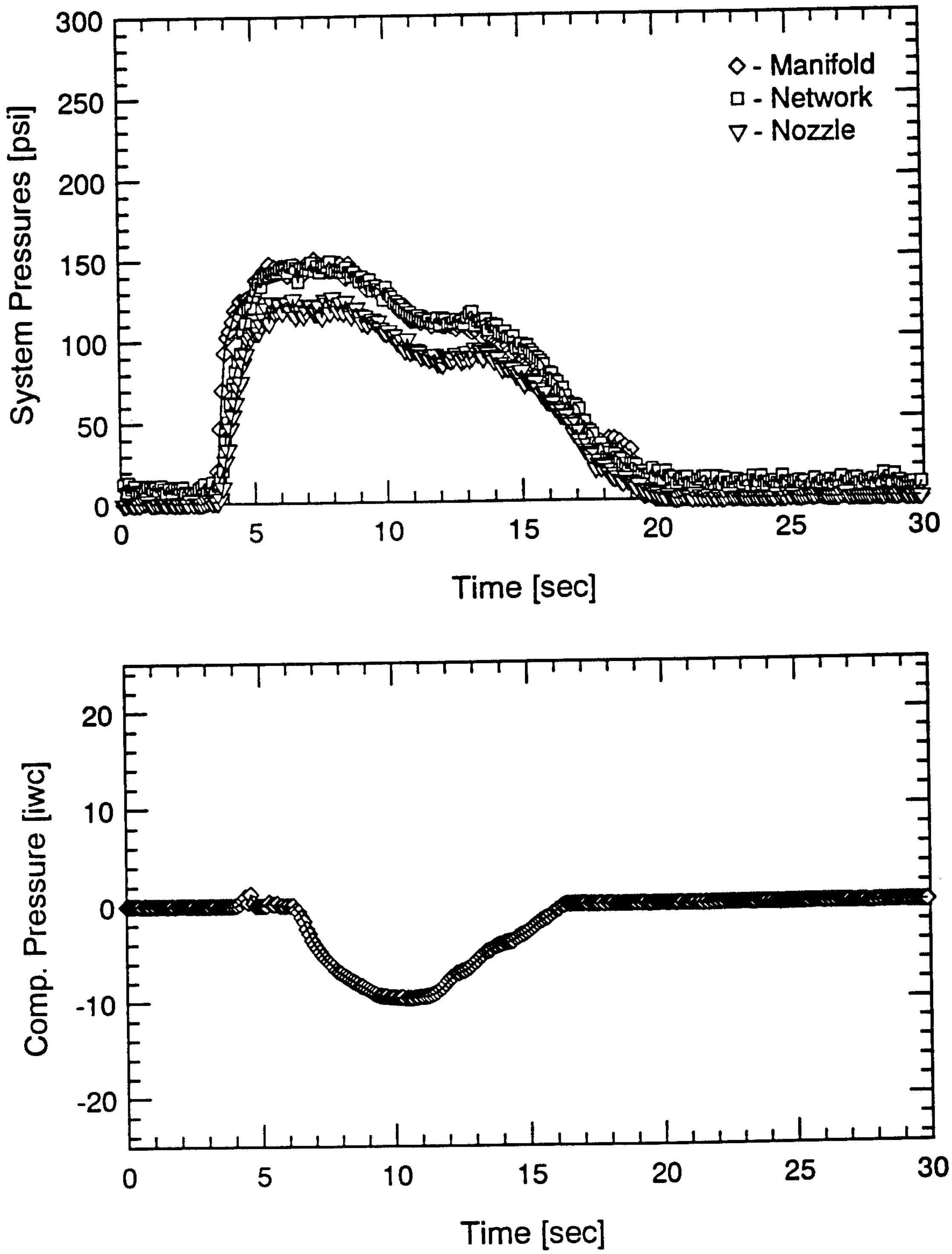




Oxygen Concentrations
TEST #26

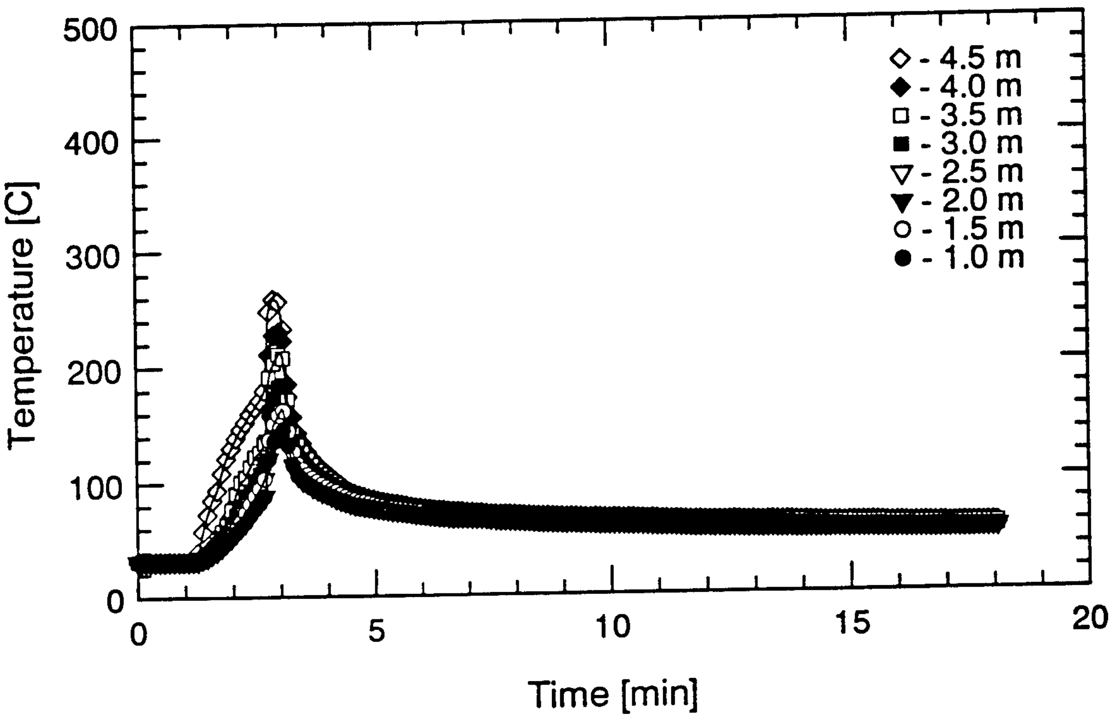


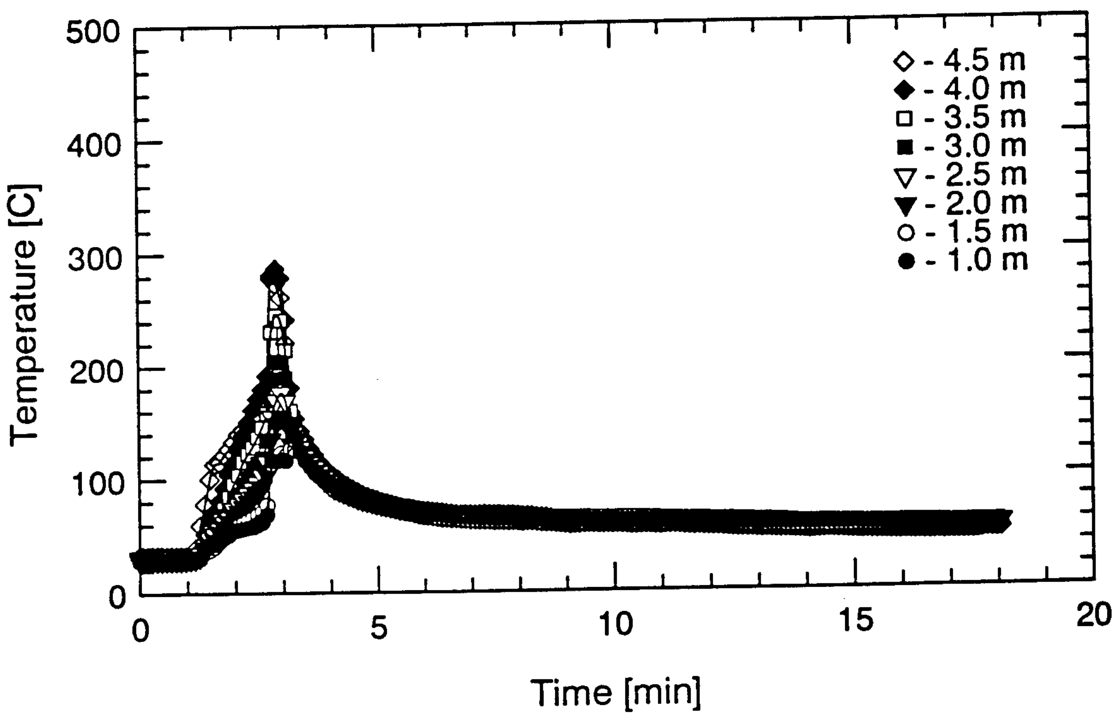




Agent and HF Concentrations
TEST #26

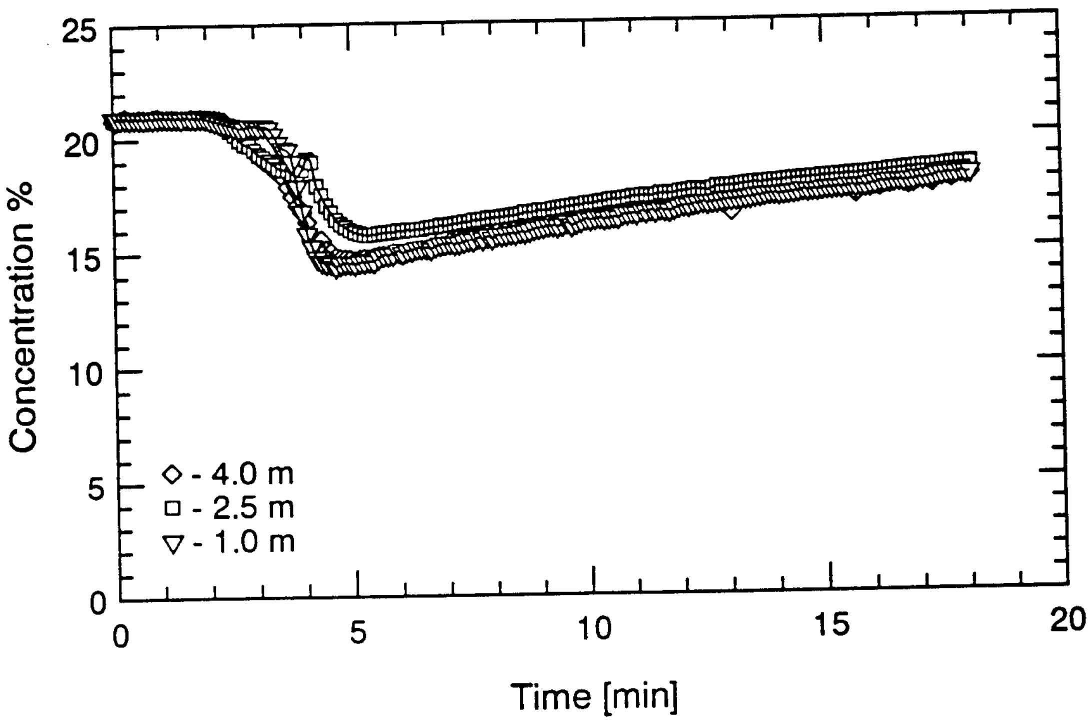


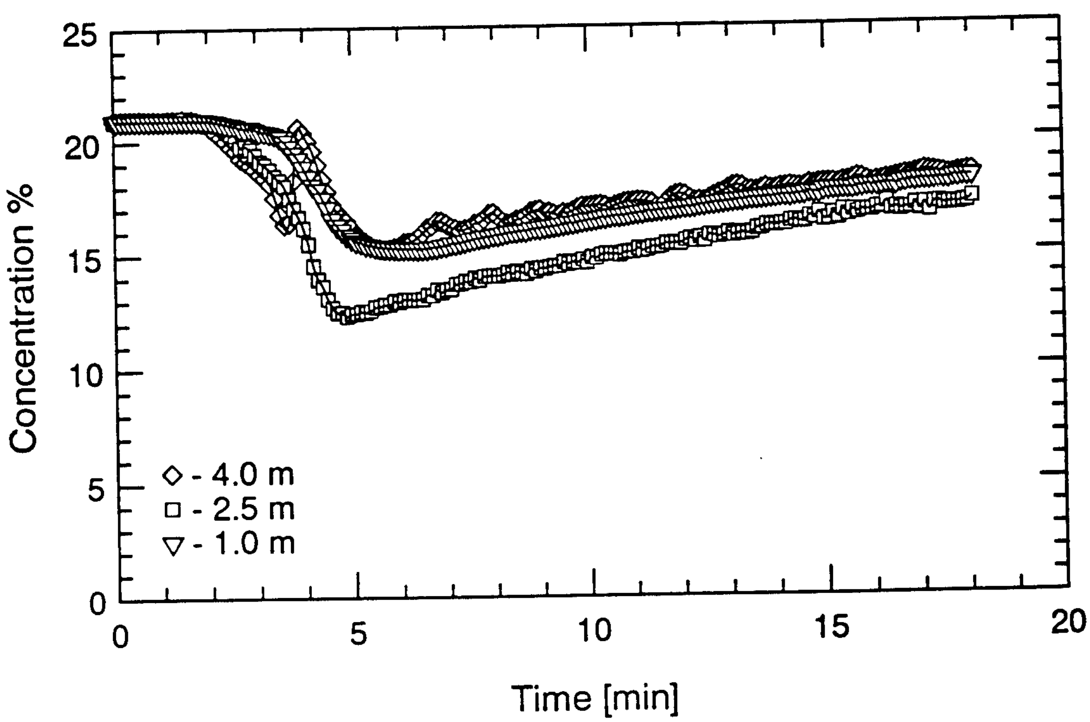

Pressure Measurements
TEST #26



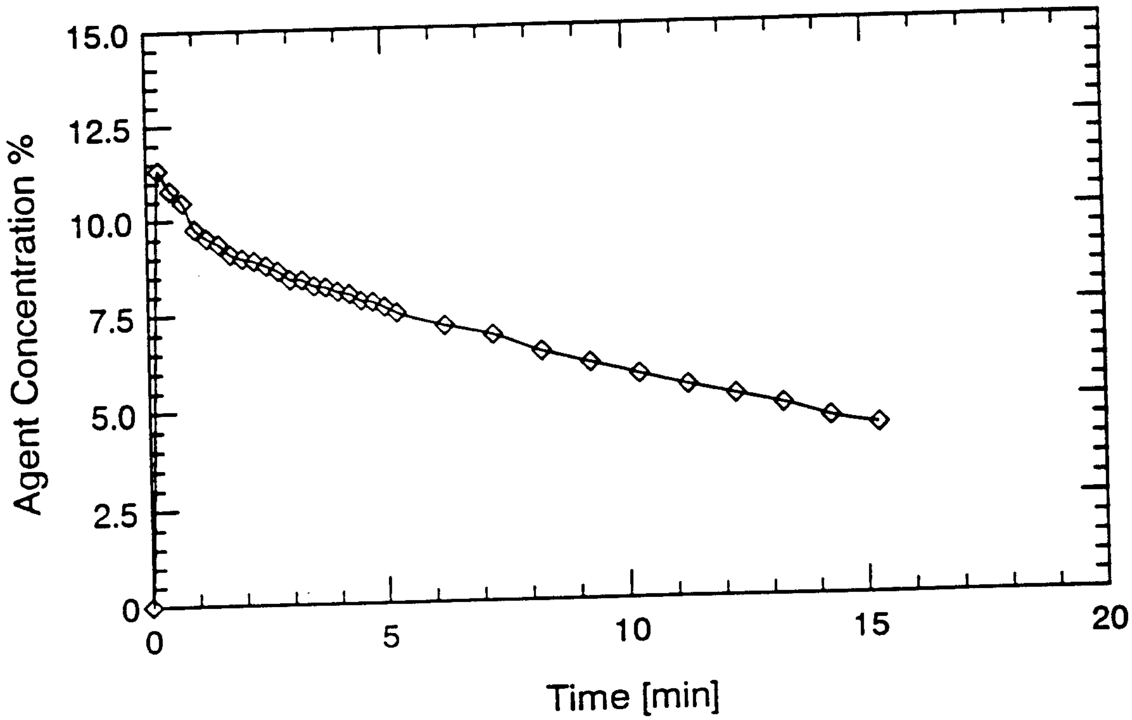



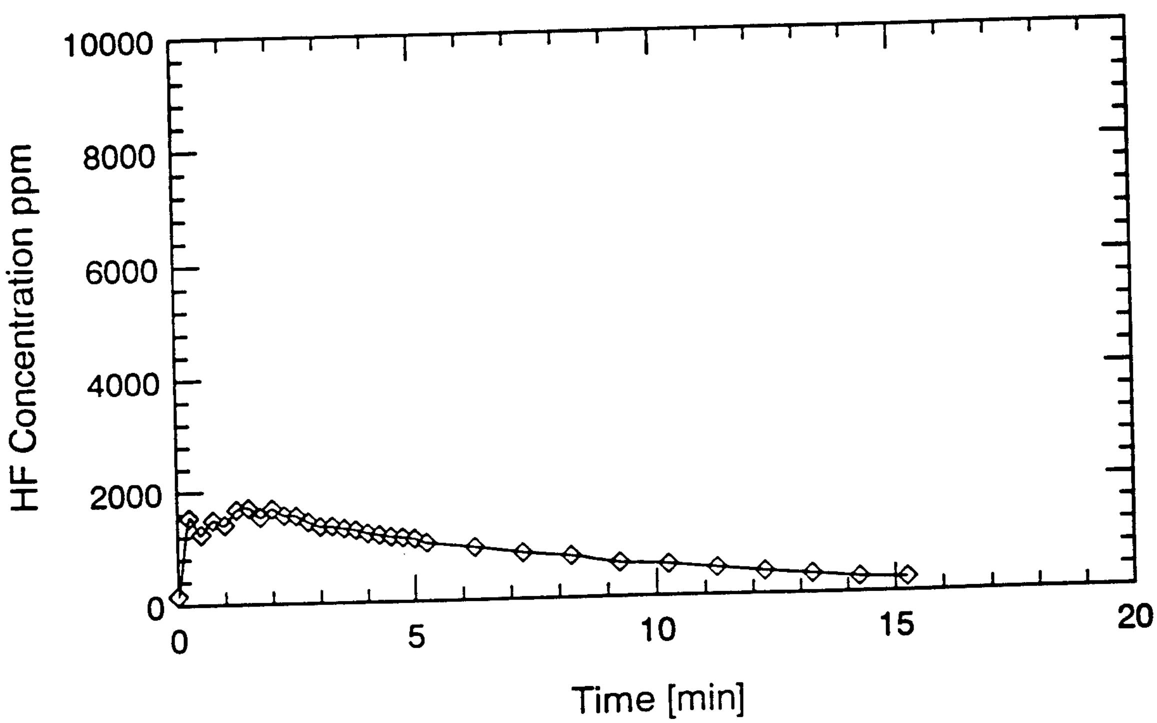

Compartment Temperatures
TEST #27



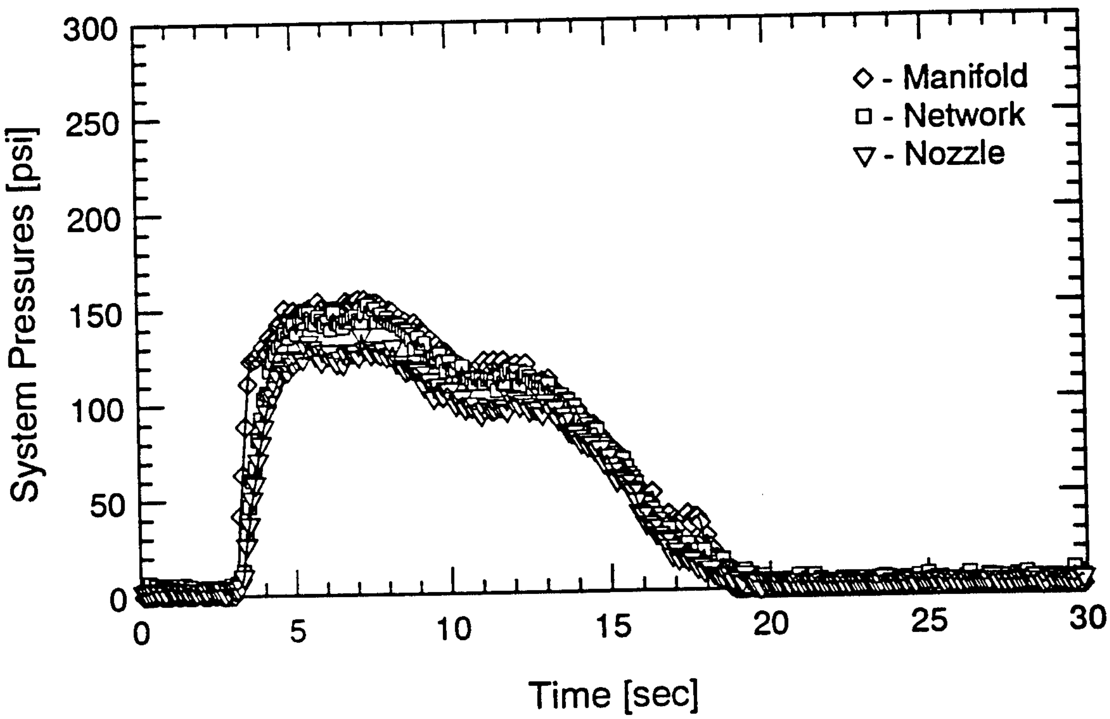



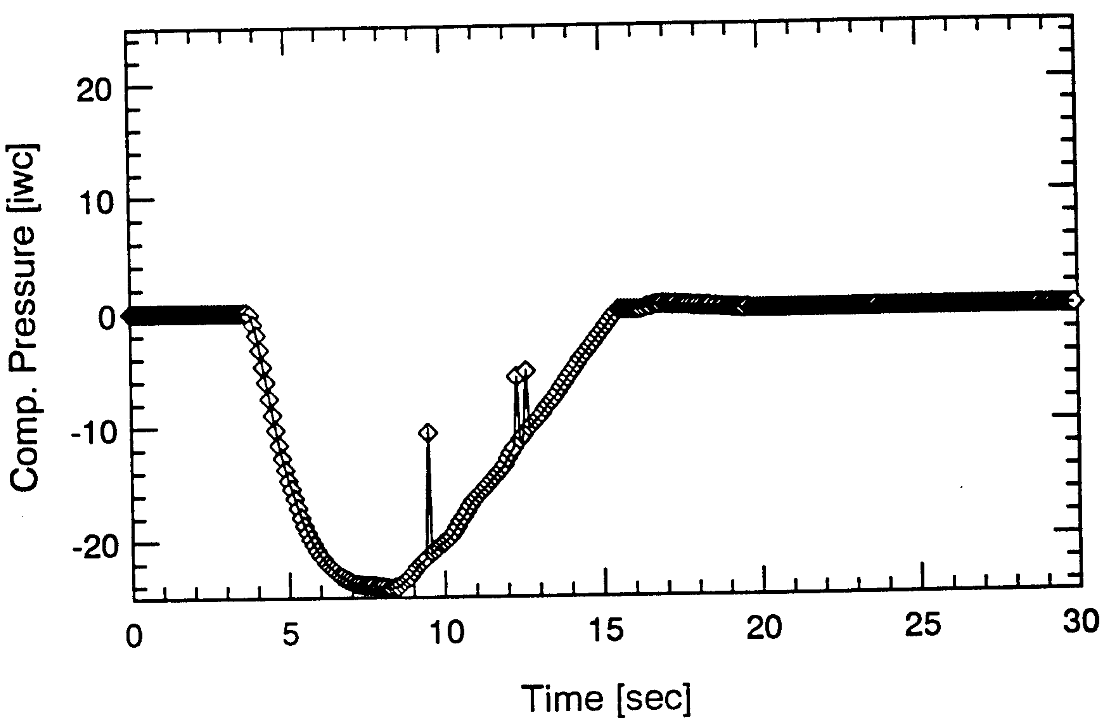

Oxygen Concentrations
TEST #27



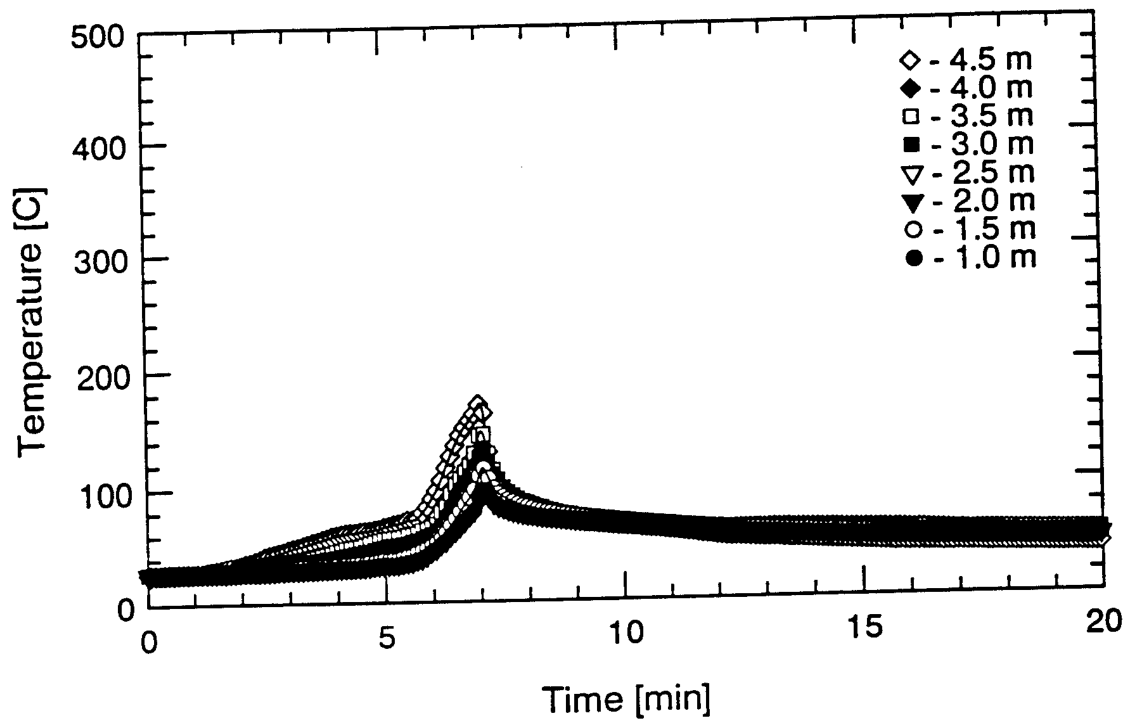



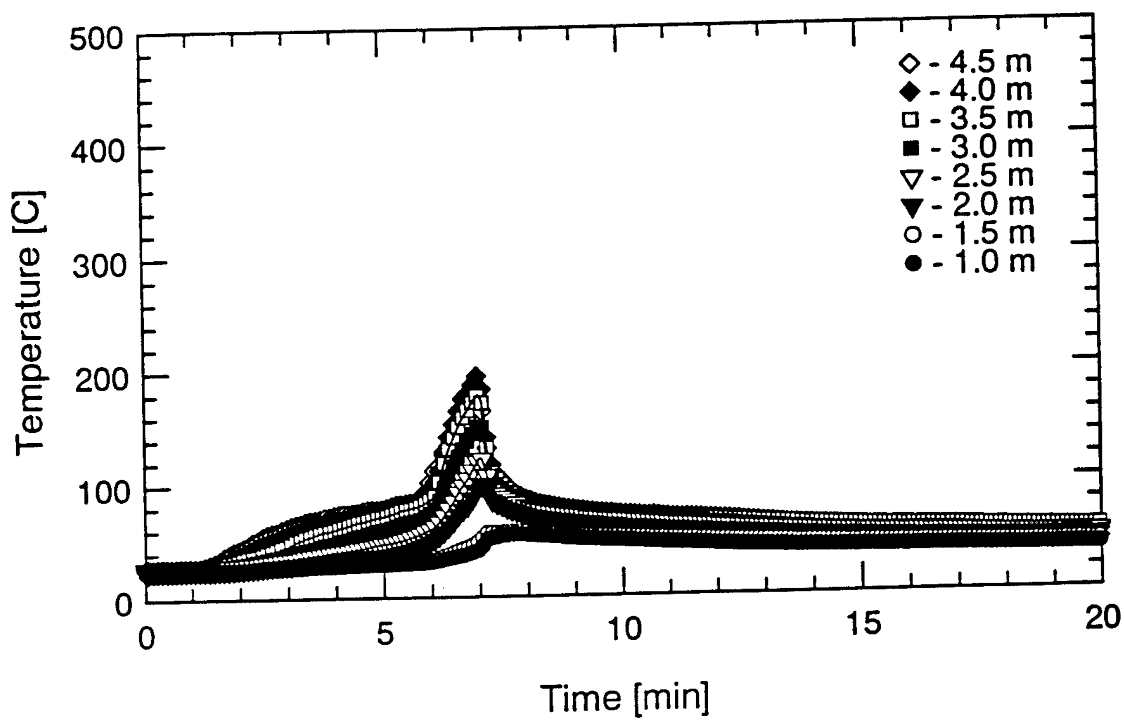

Agent and HF Concentrations
TEST #27



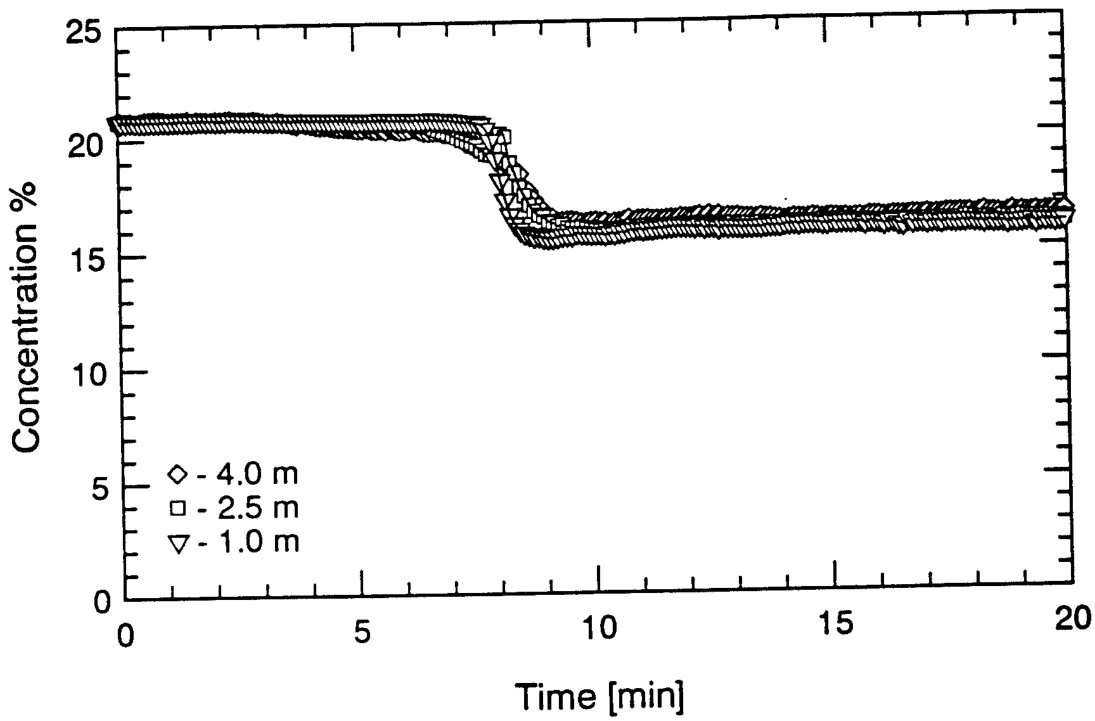



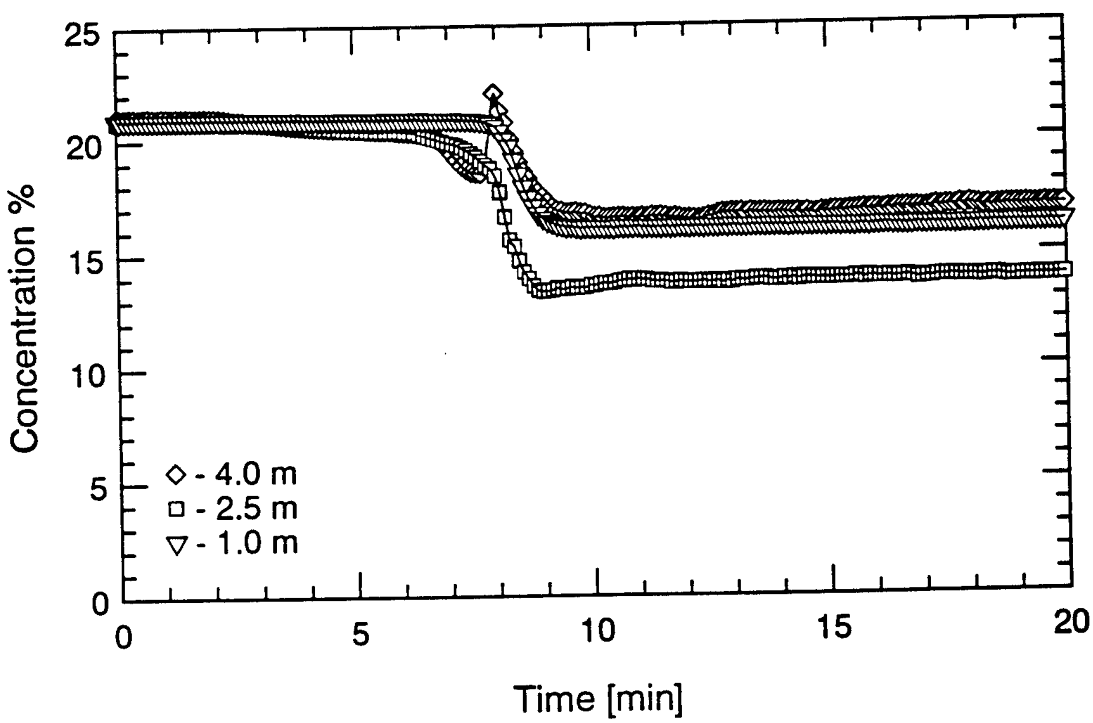

Pressure Measurements
TEST #27



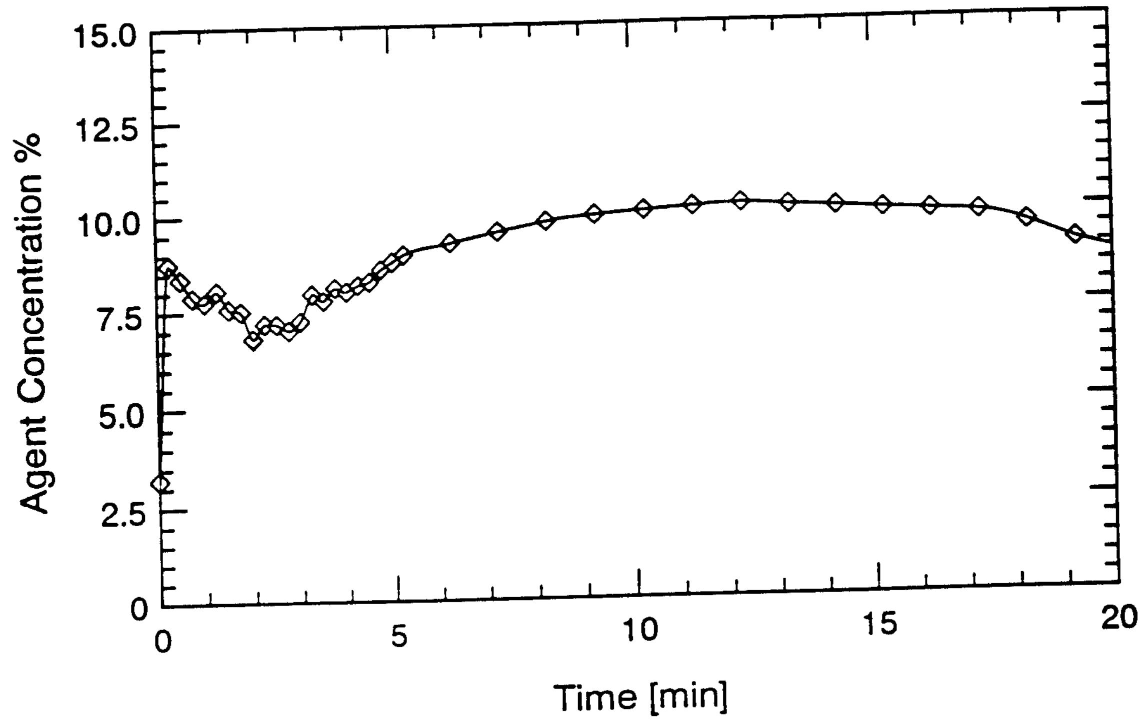



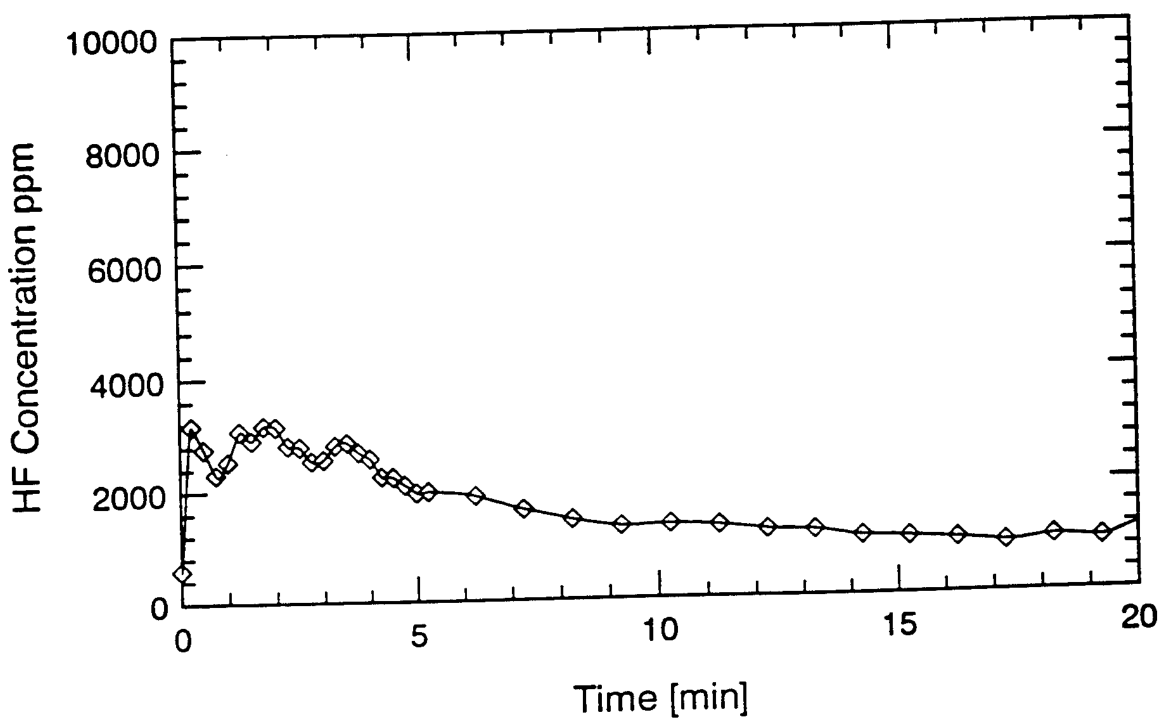

Compartment Temperatures
TEST #28



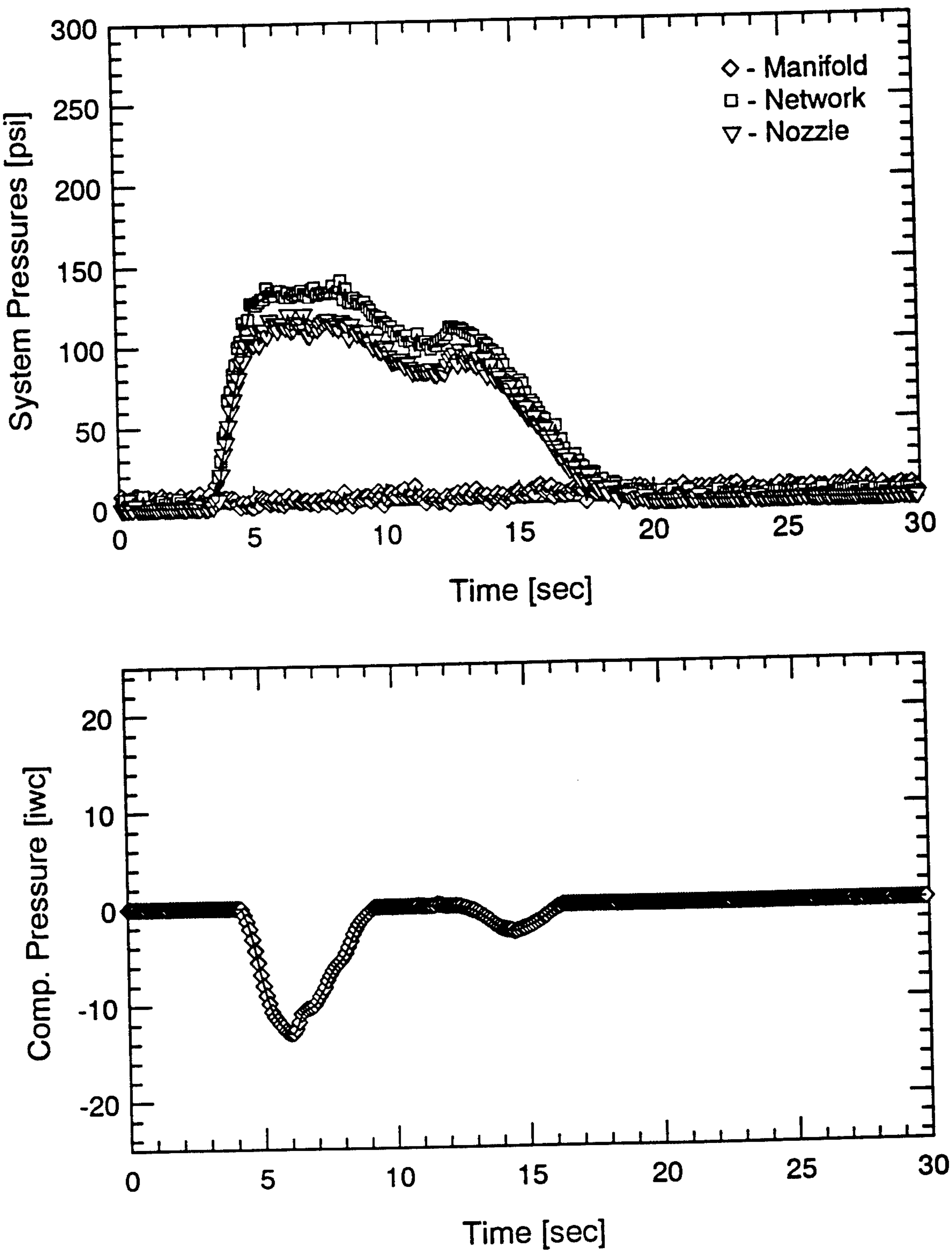




Oxygen Concentrations
TEST #28

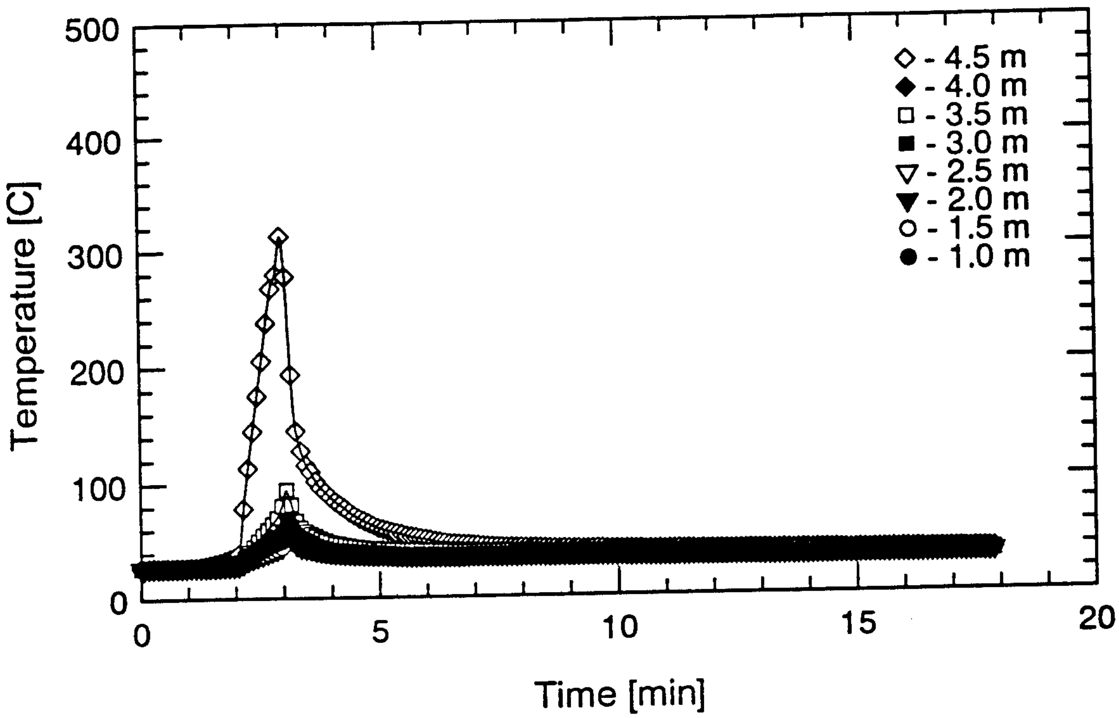


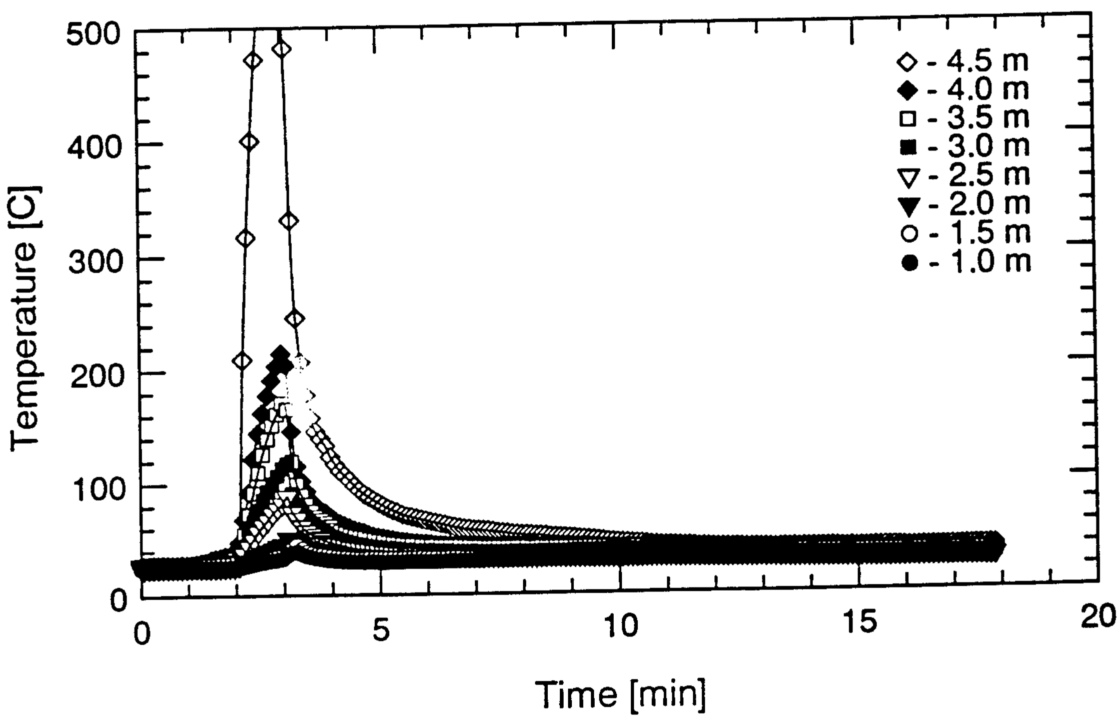




Agent and HF Concentrations
TEST #28

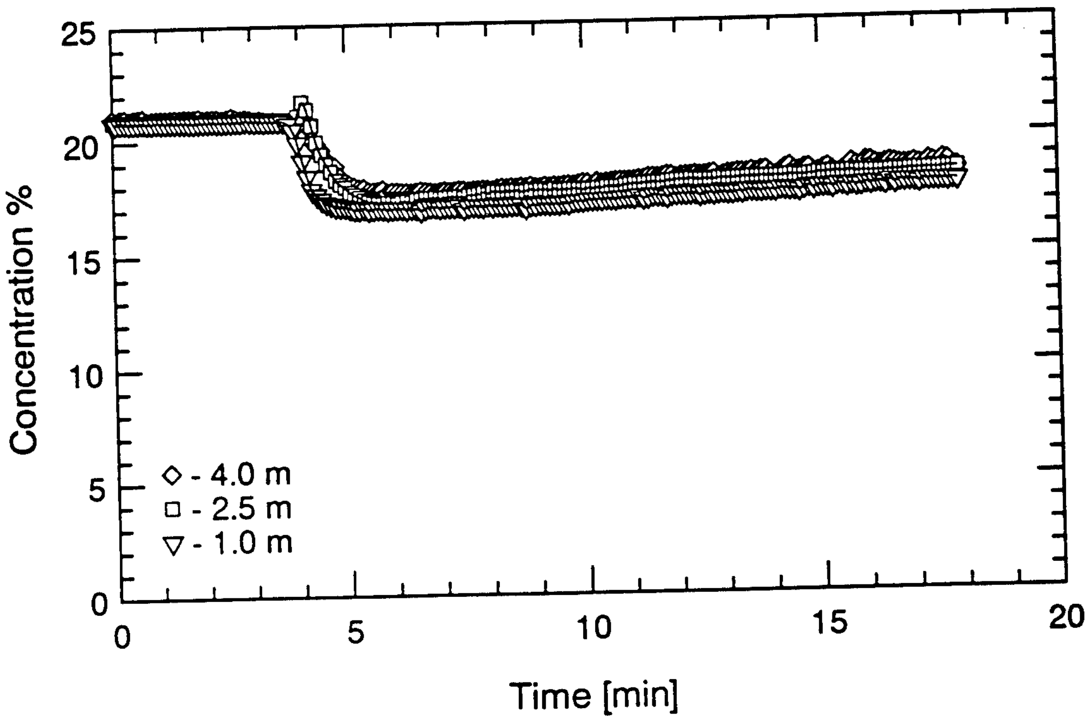


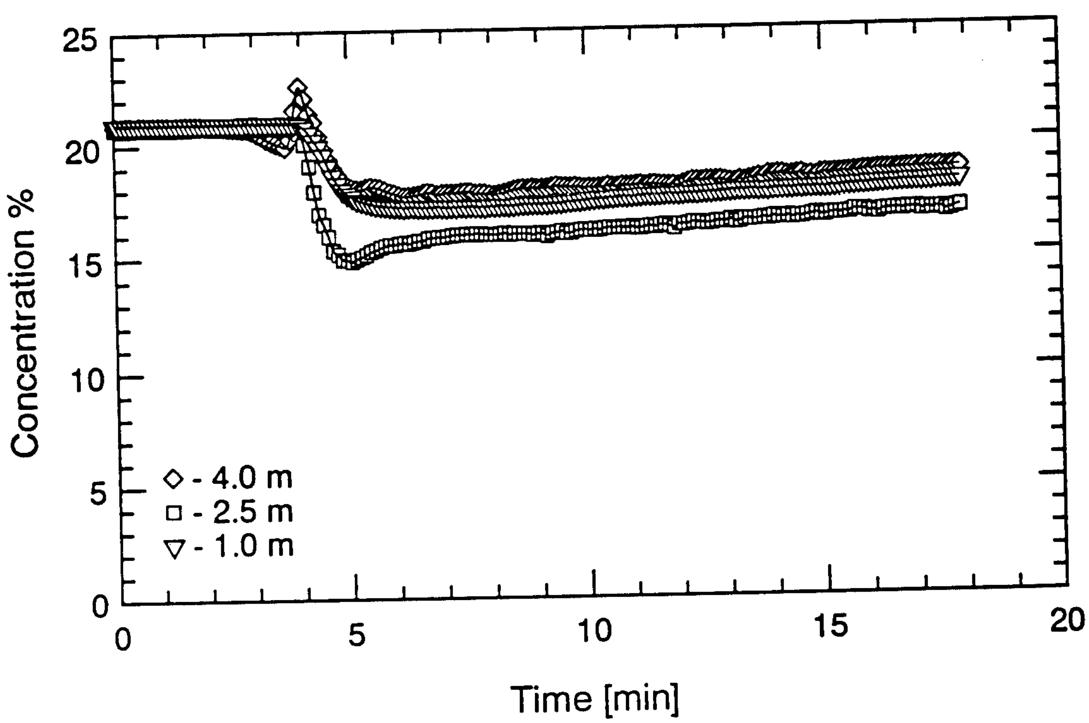

Pressure Measurements
TEST #28



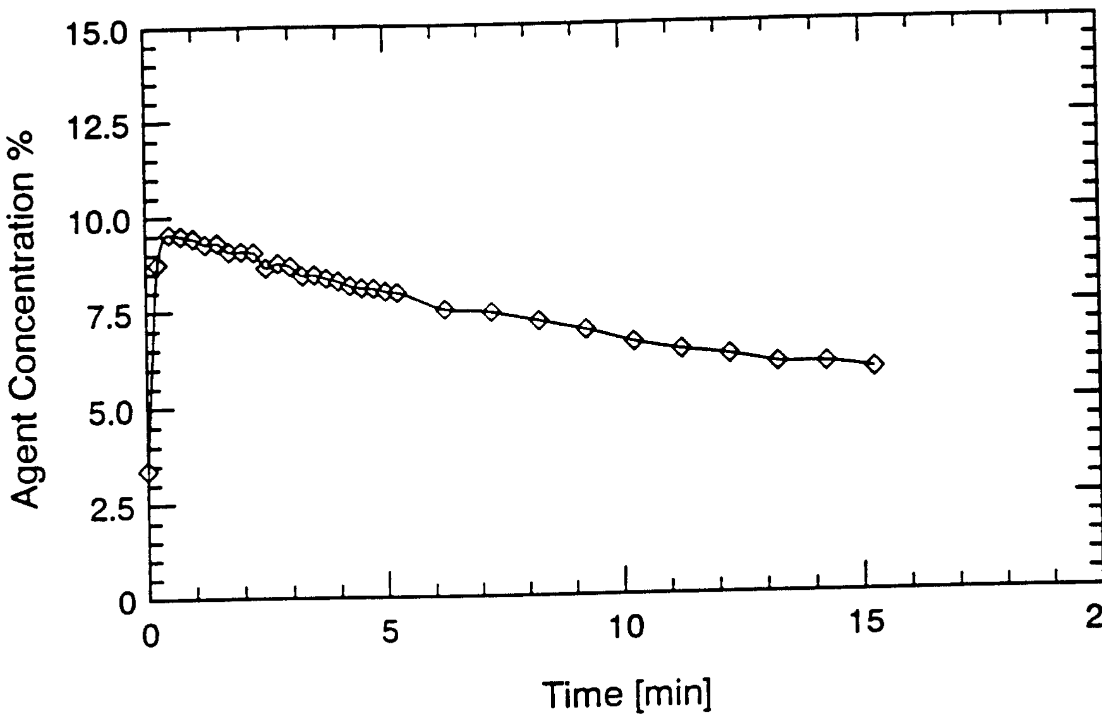



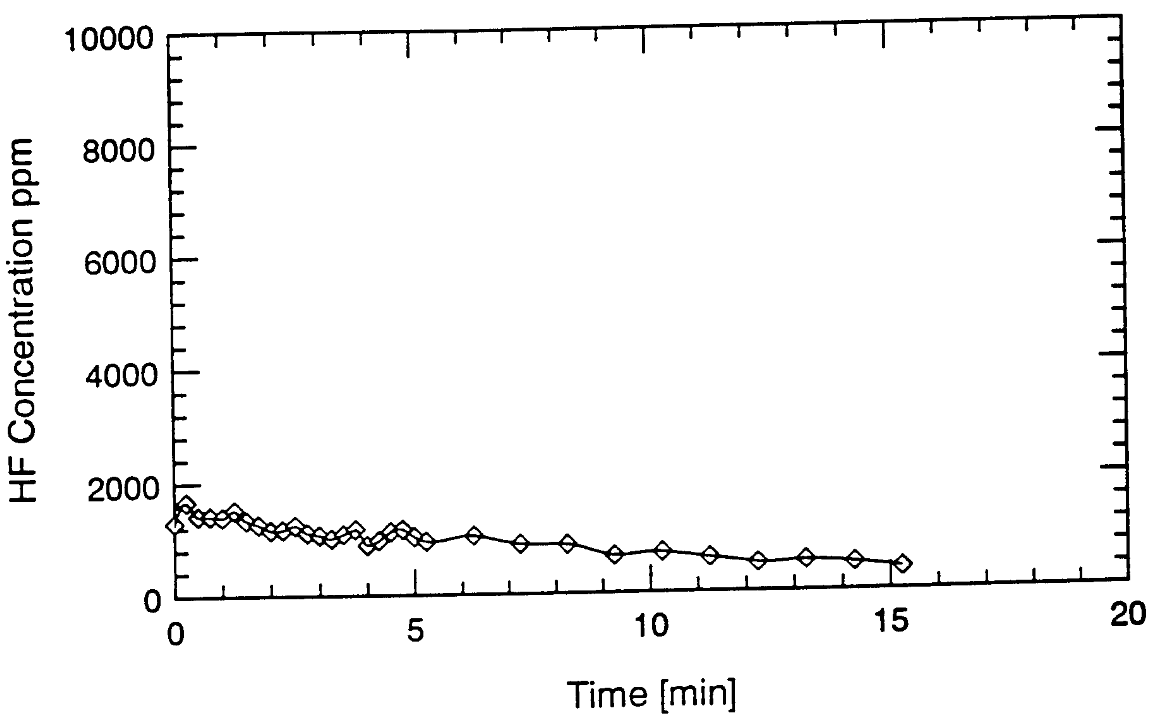

Compartment Temperatures
TEST #29



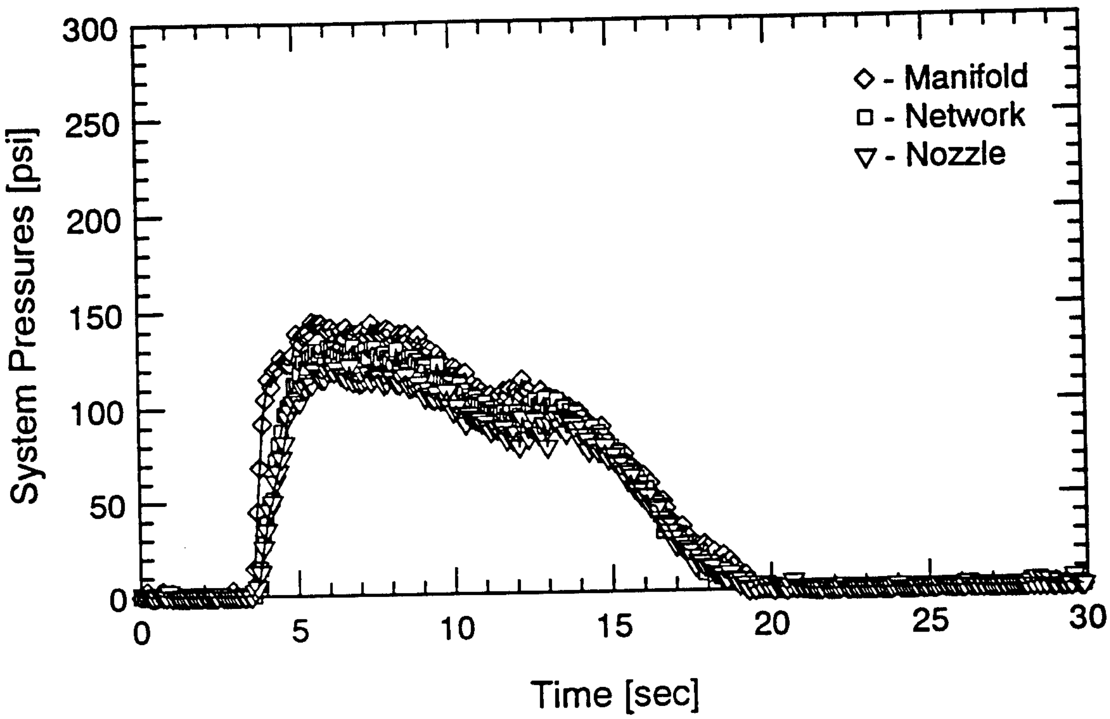



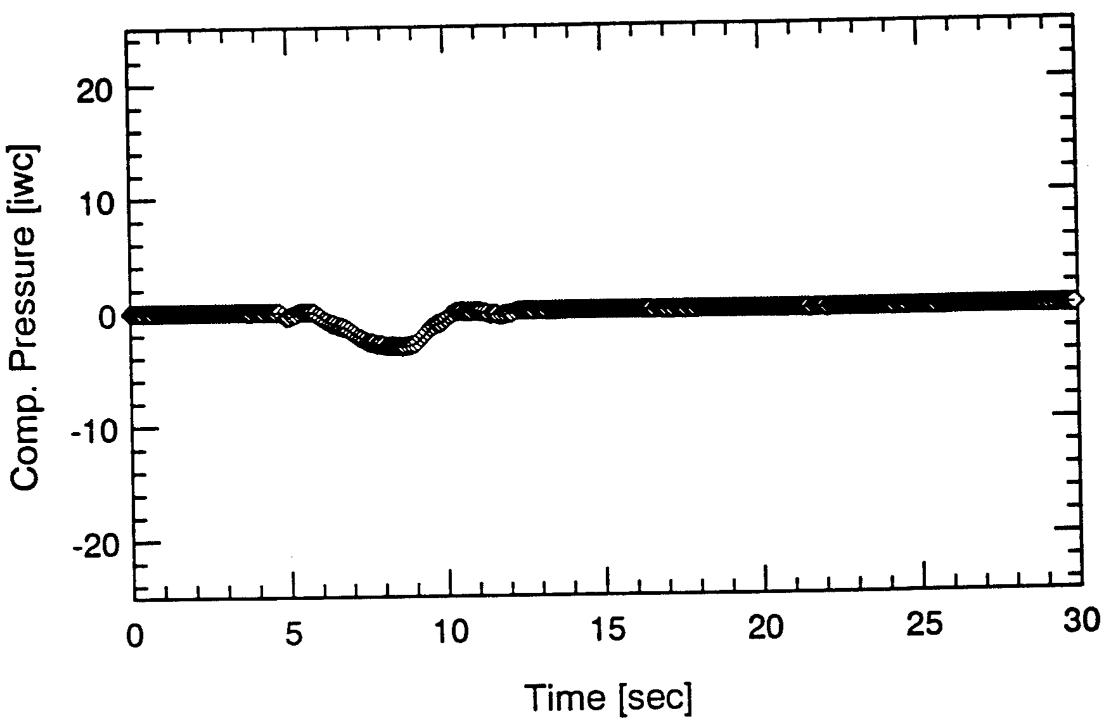

Oxygen Concentrations
TEST #29



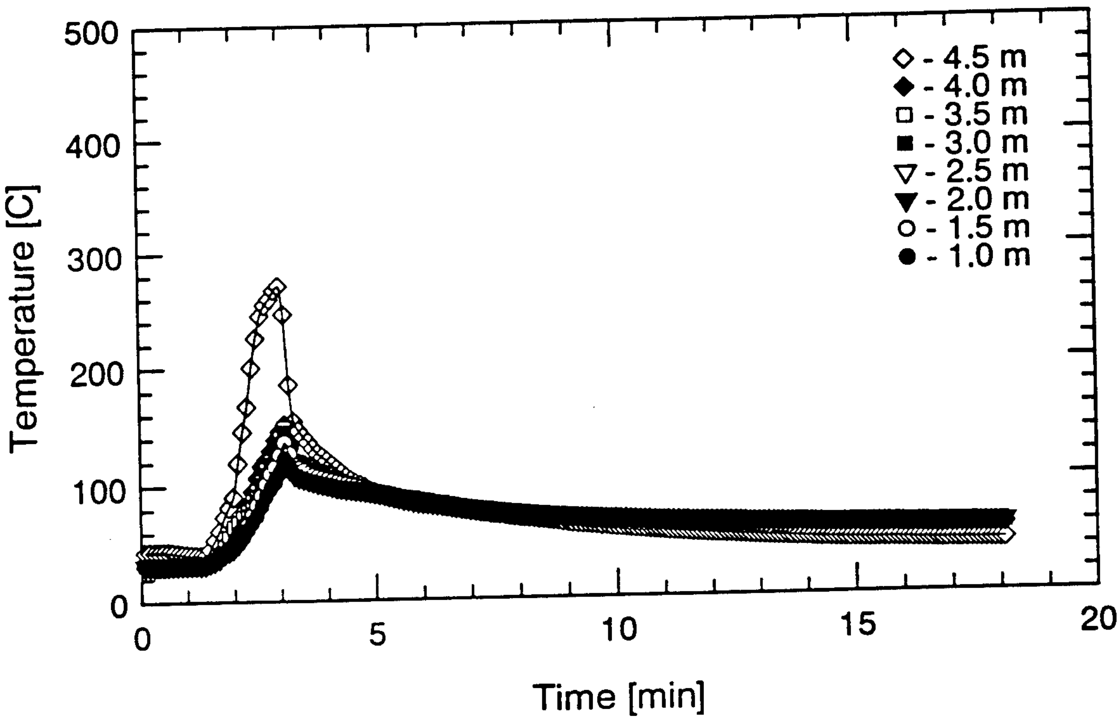



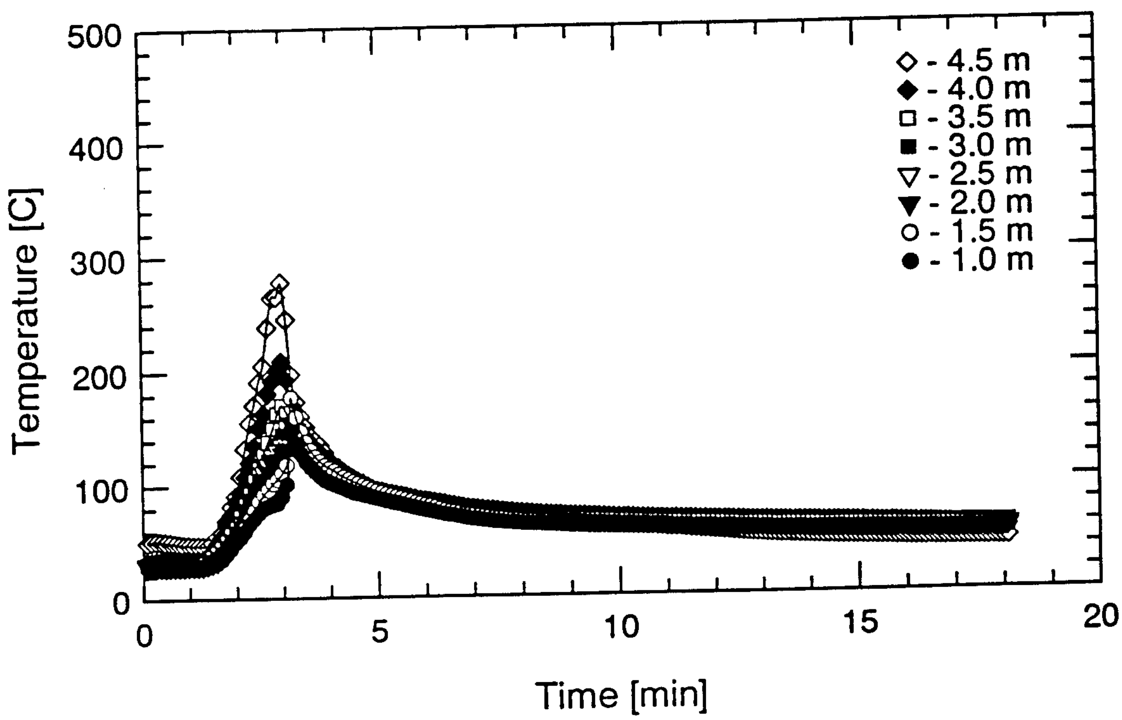

Agent and HF Concentrations
TEST #29



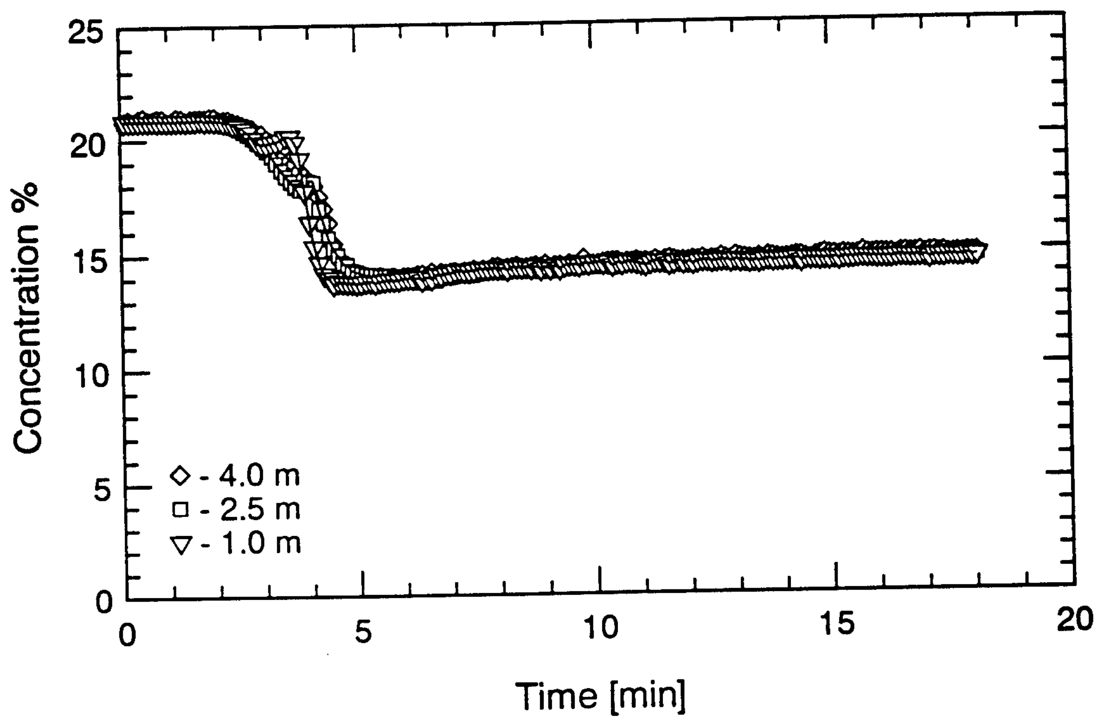



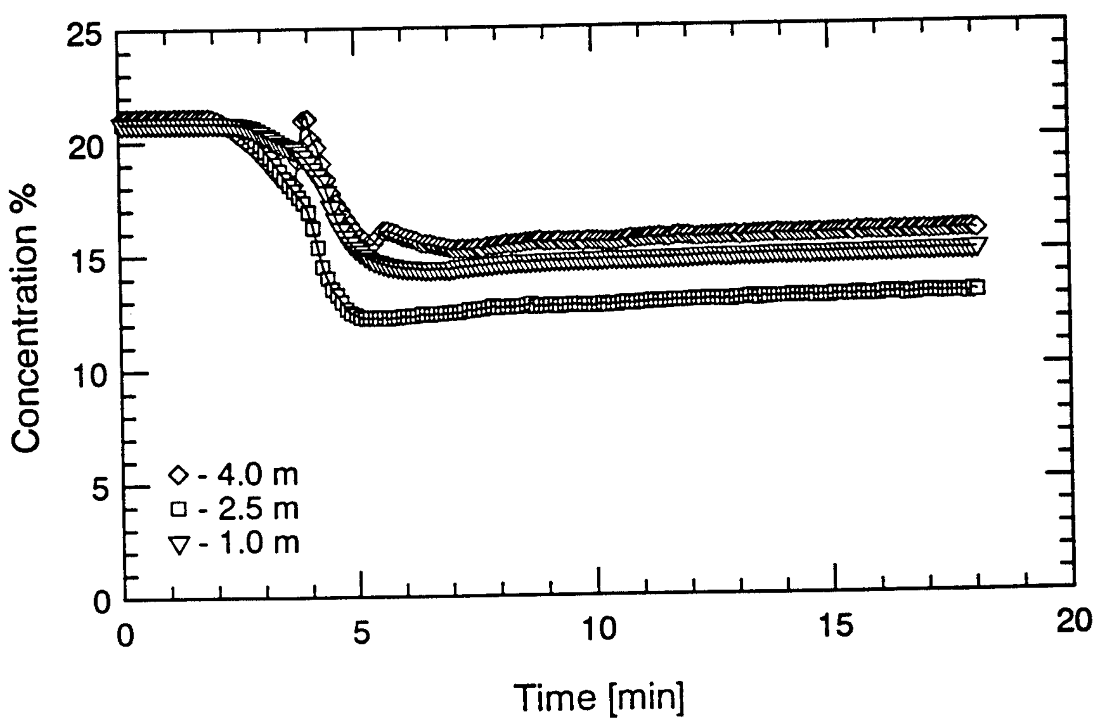

Pressure Measurements
TEST #29



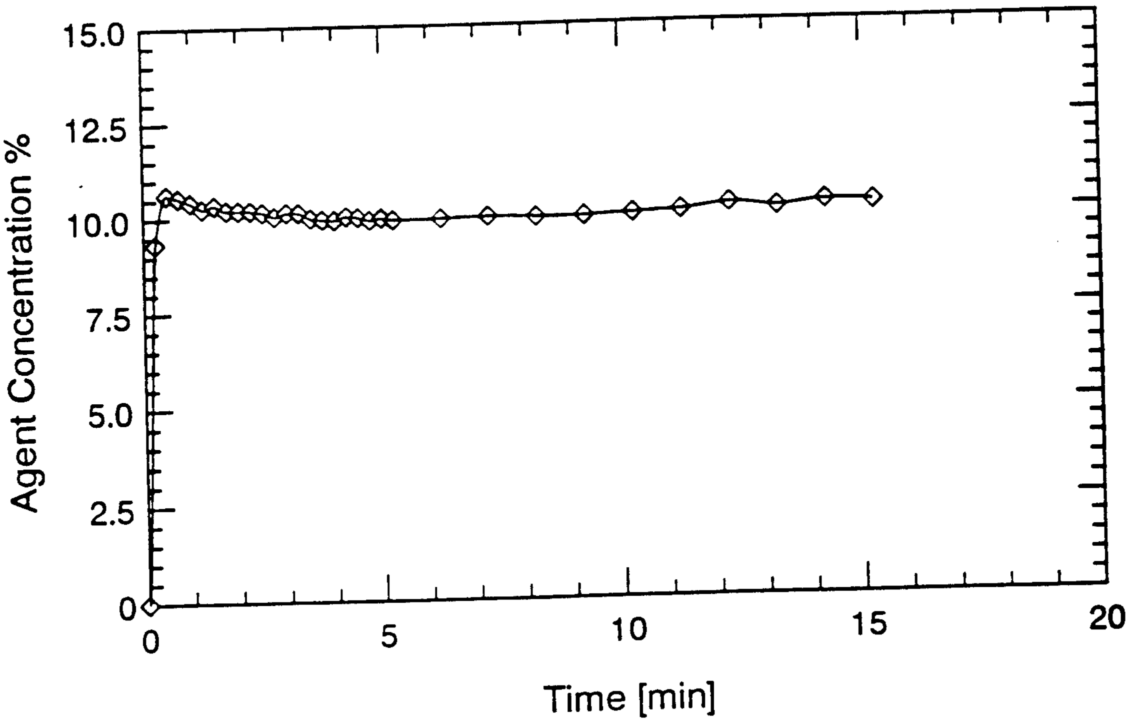



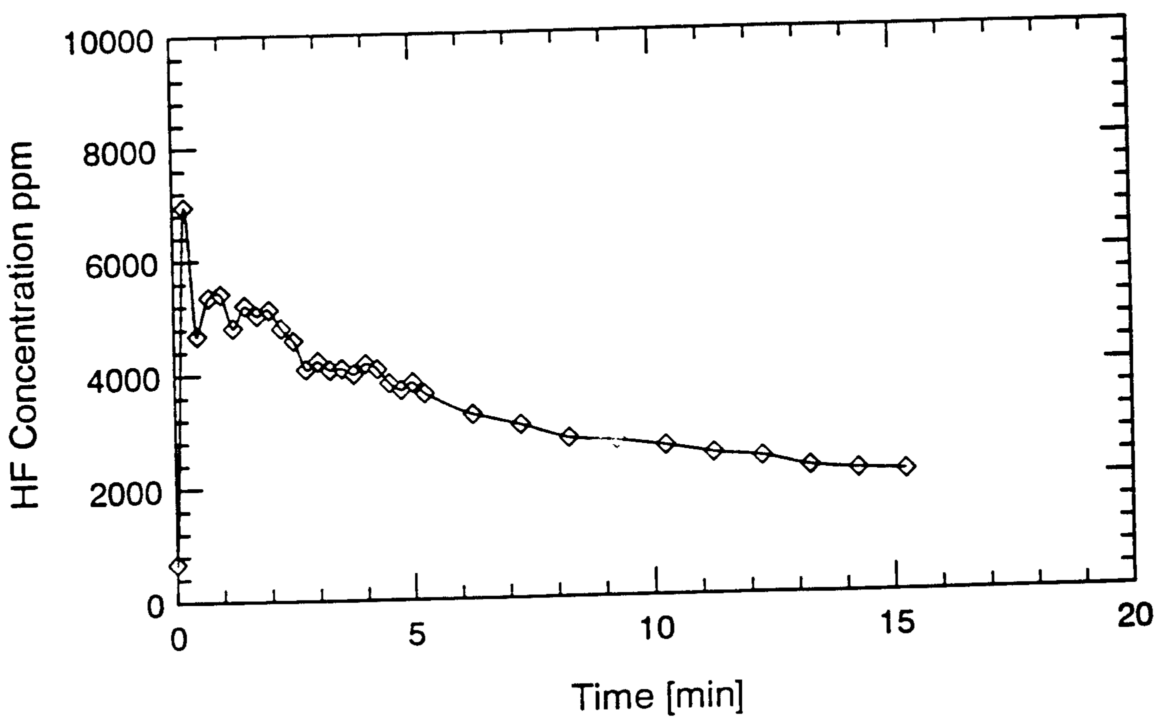

Compartment Temperatures
TEST #30



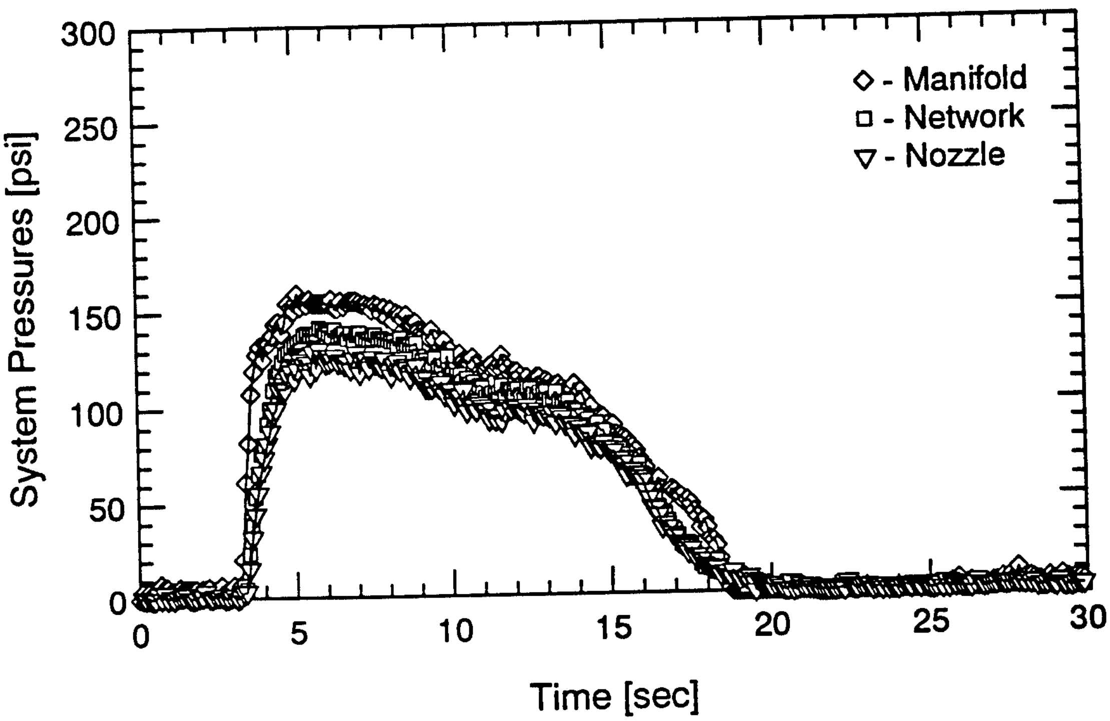



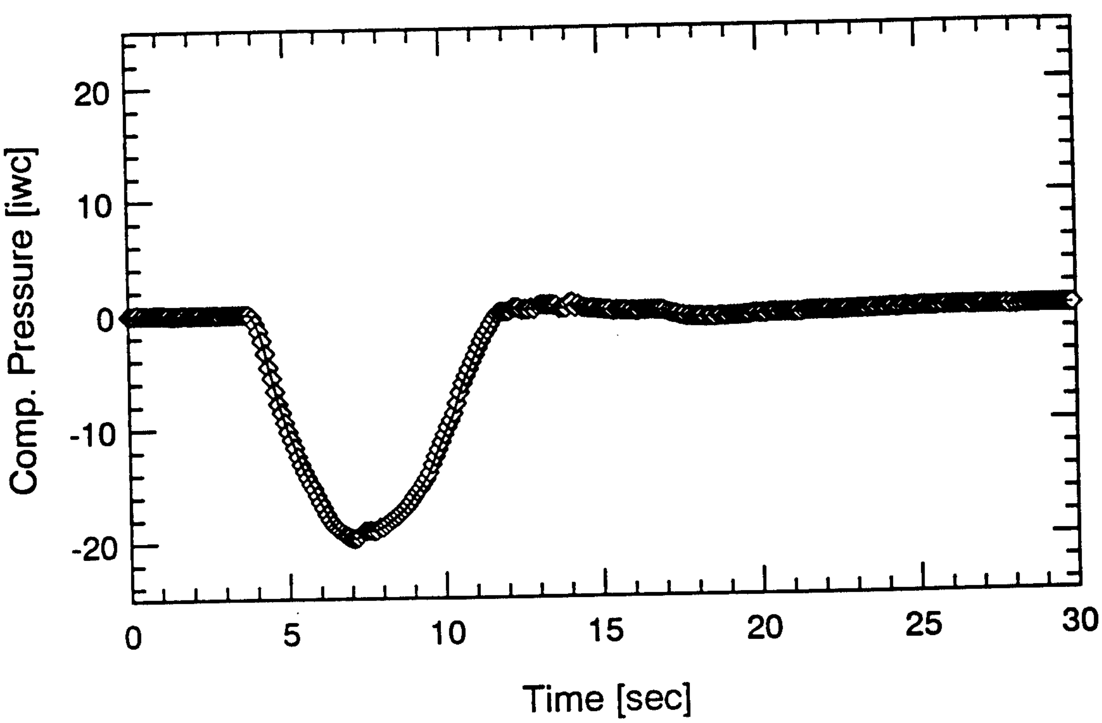

Oxygen Concentrations
TEST #30



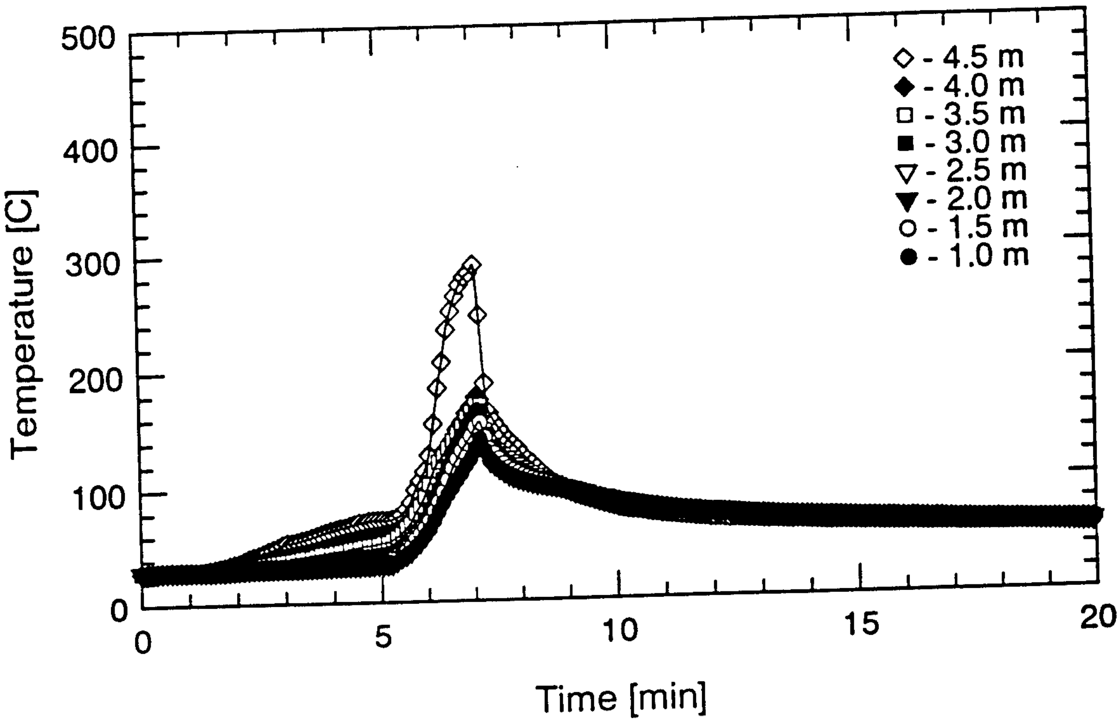



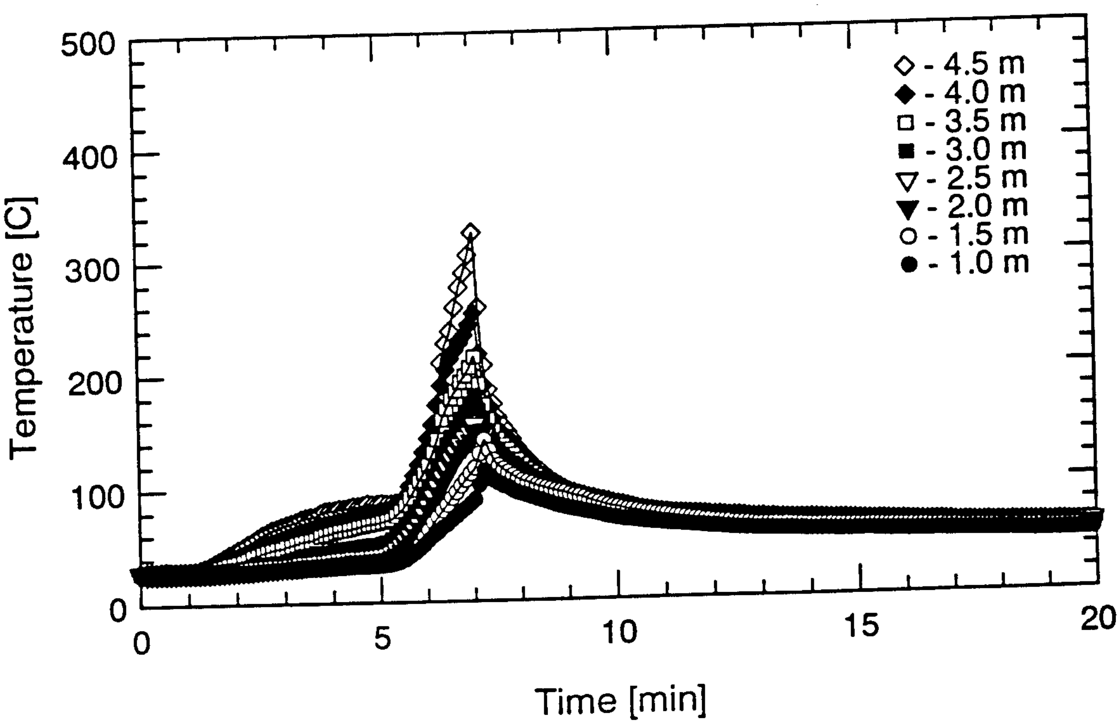

Agent and HF Concentrations
TEST #30



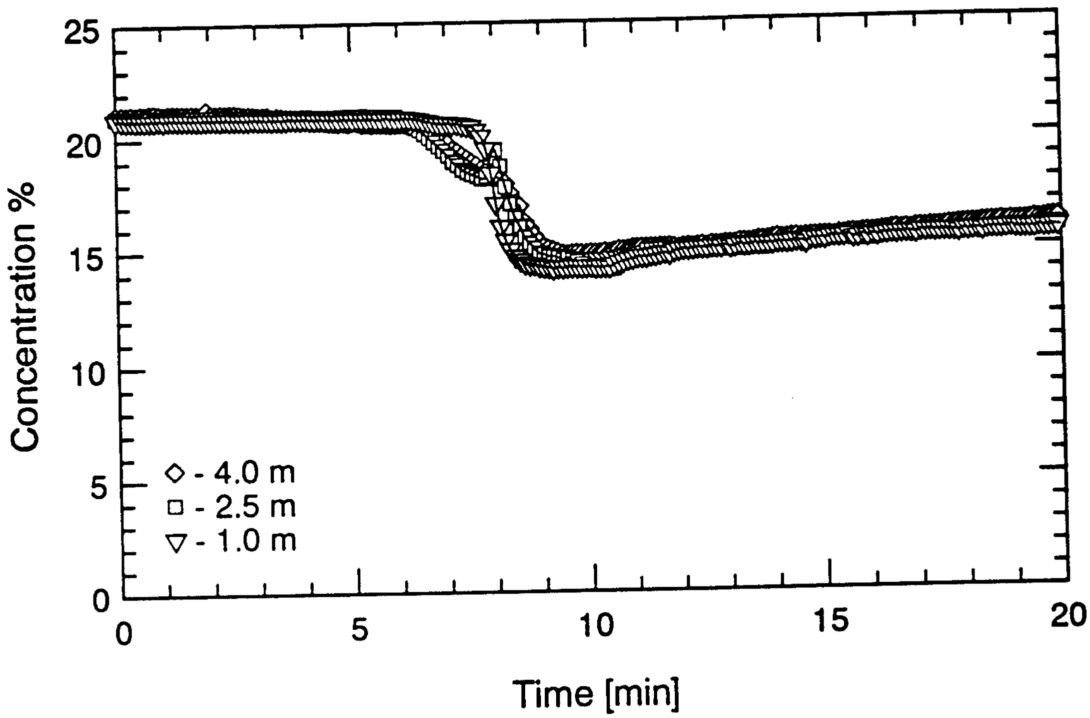



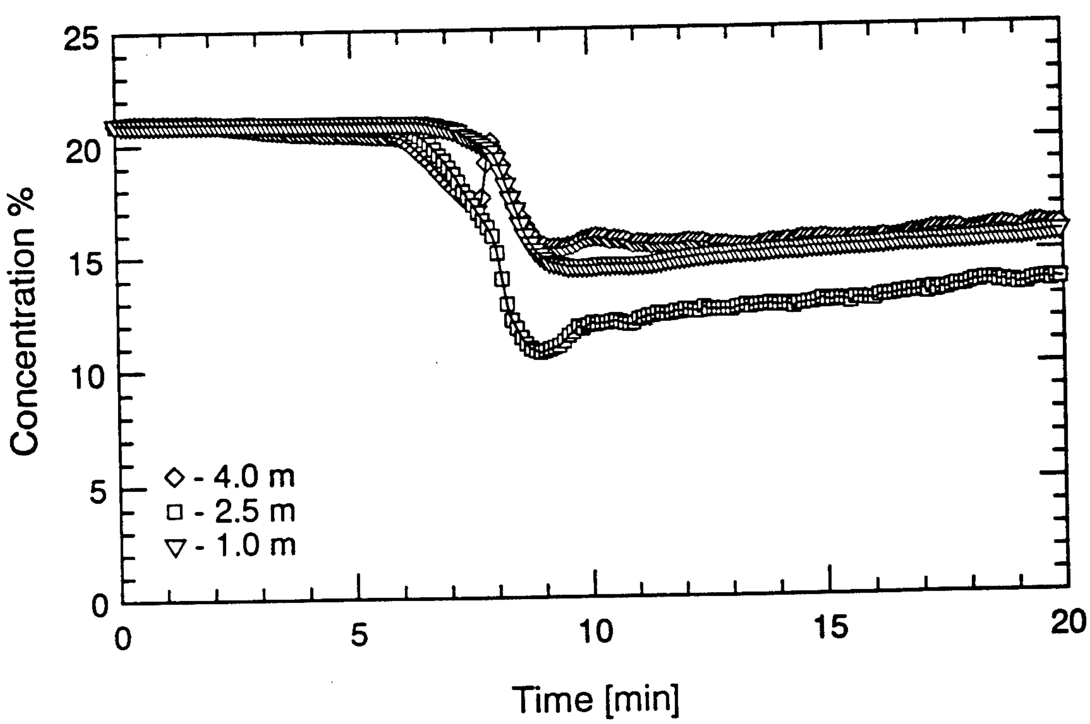

Pressure Measurements
TEST #30



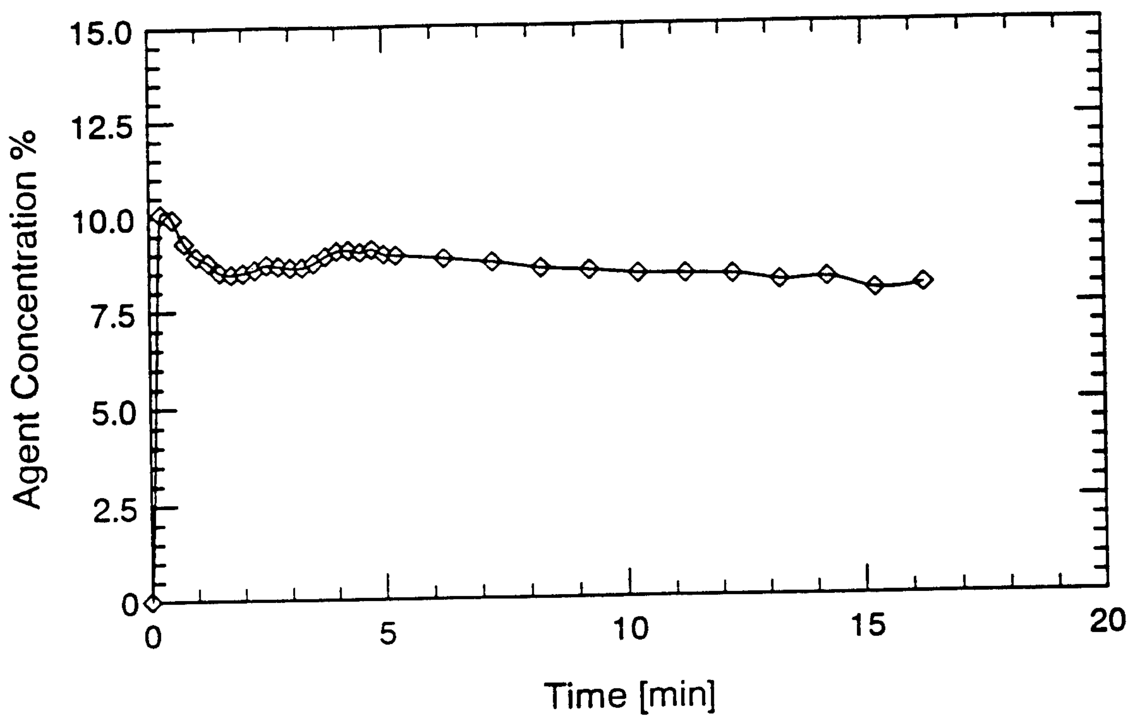



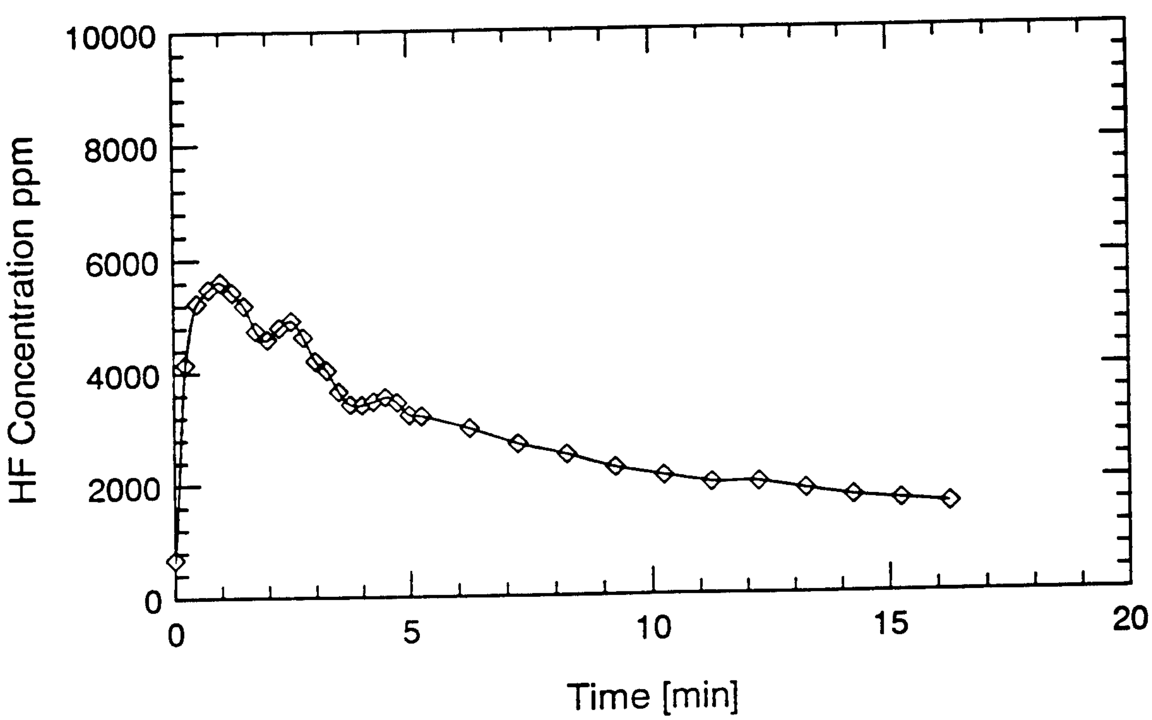

Compartment Temperatures
TEST #31



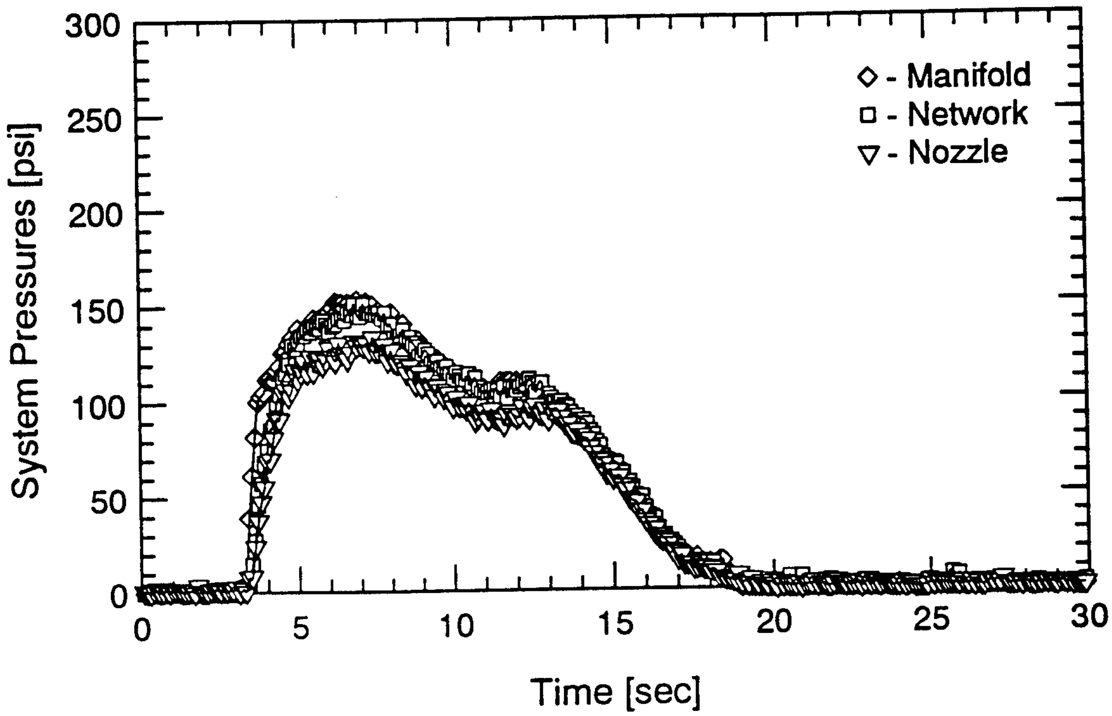



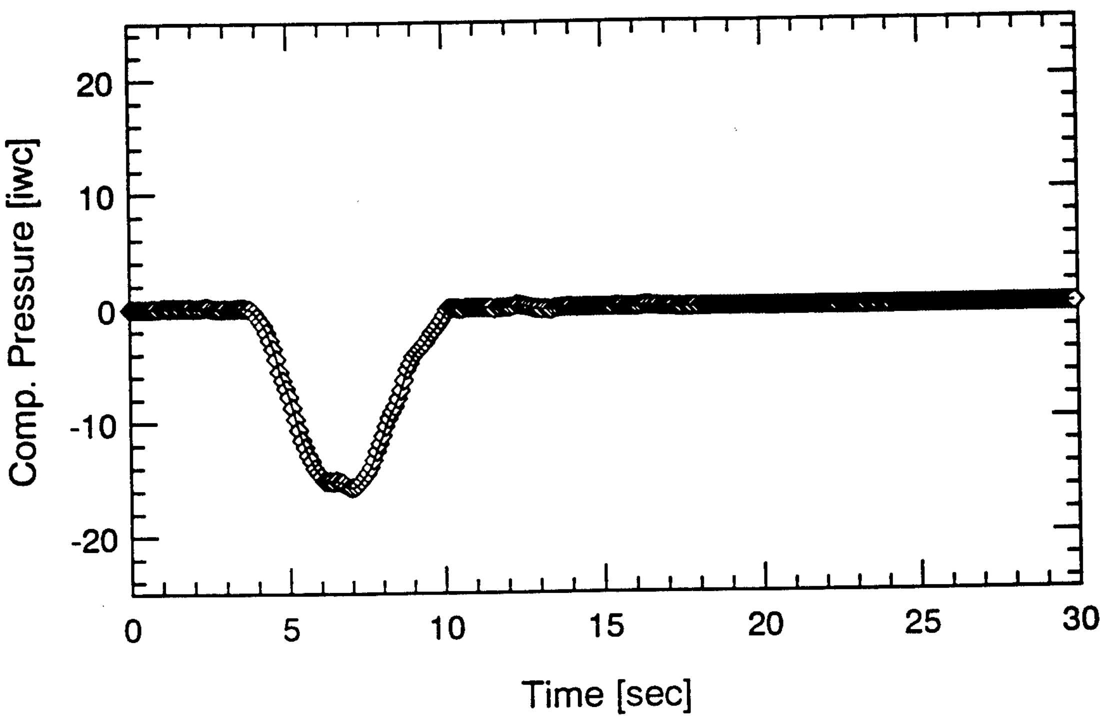

Oxygen Concentrations
TEST #31



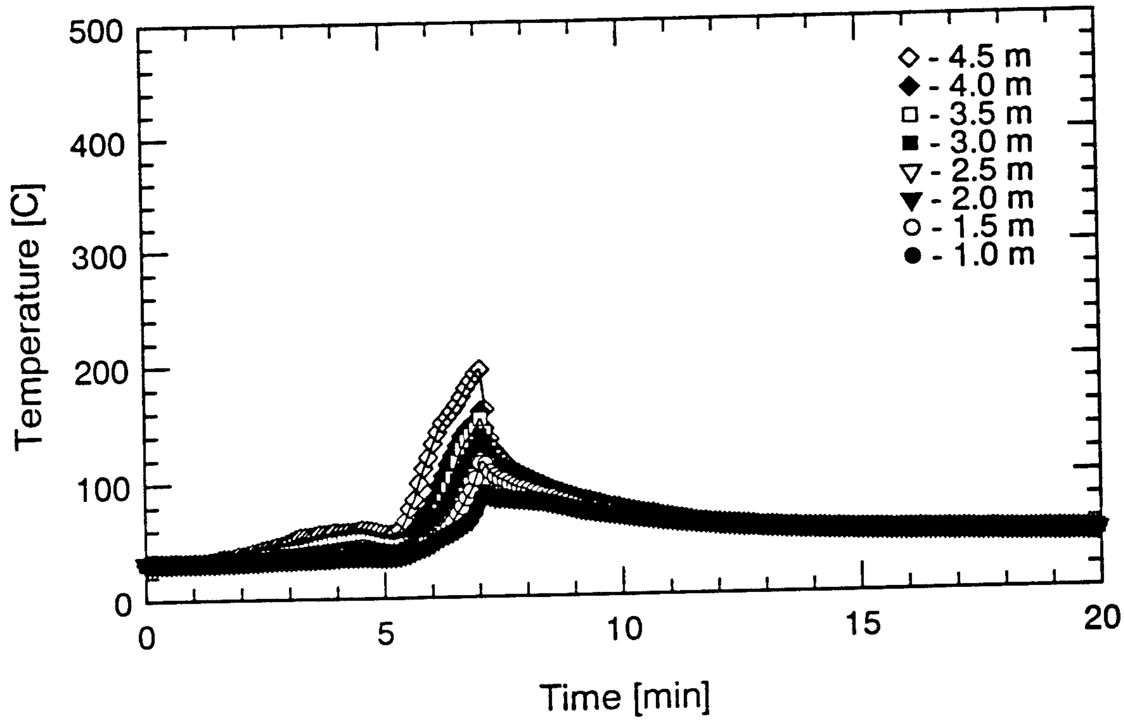



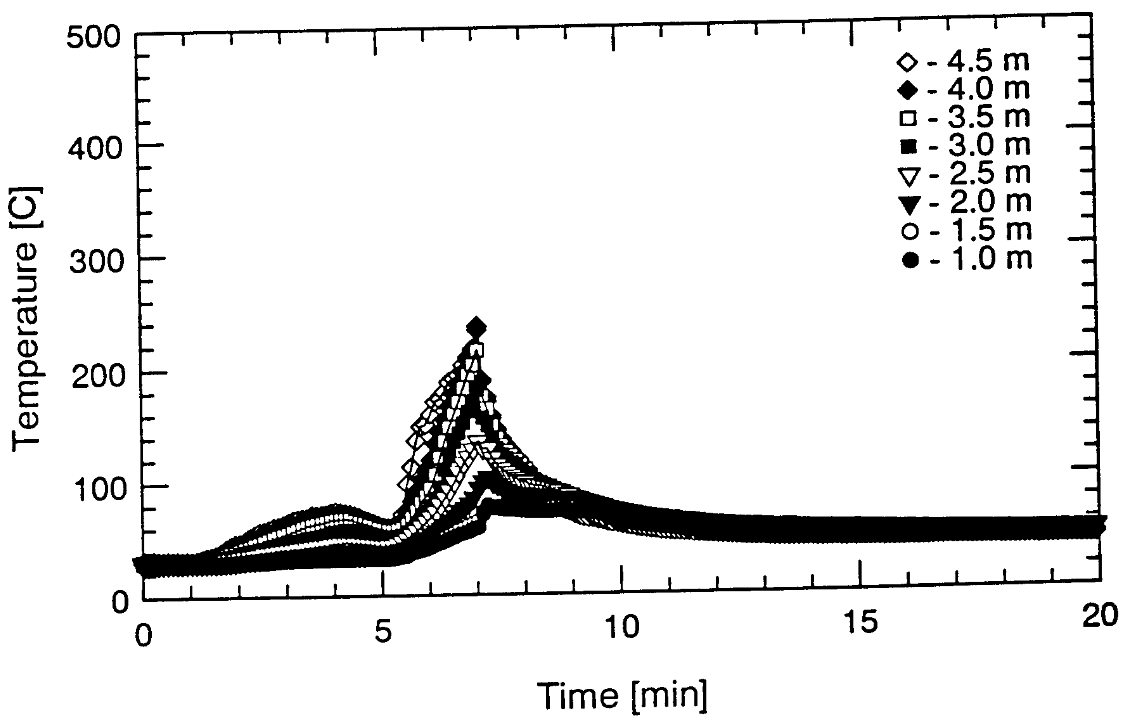

Agent and HF Concentrations
TEST #31



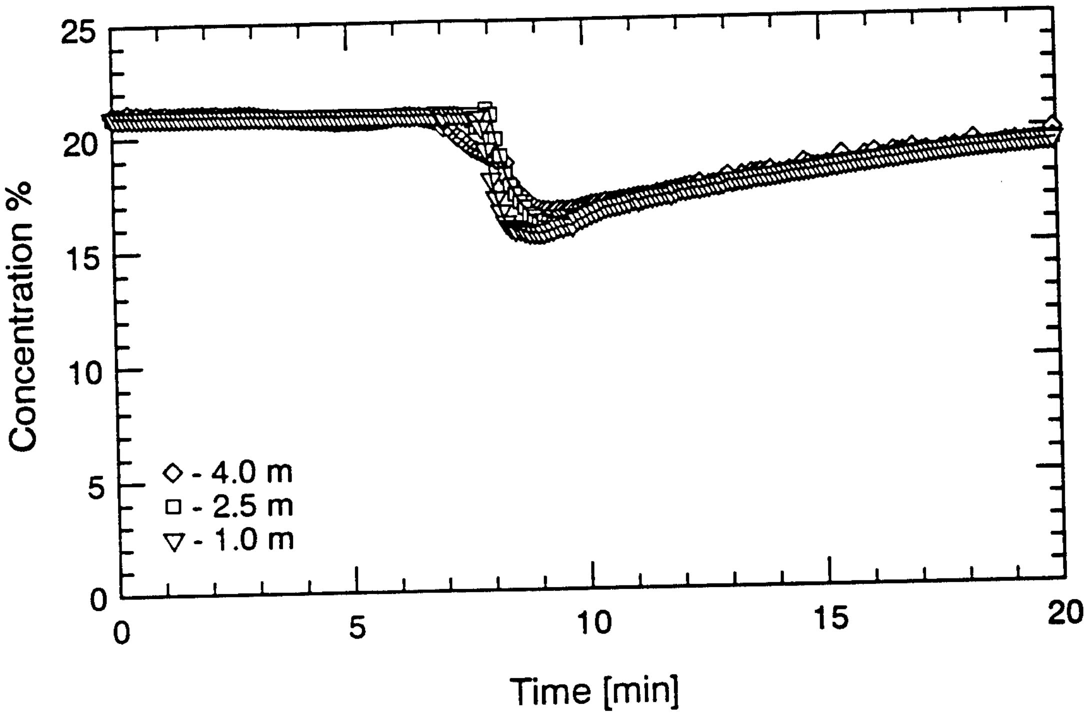



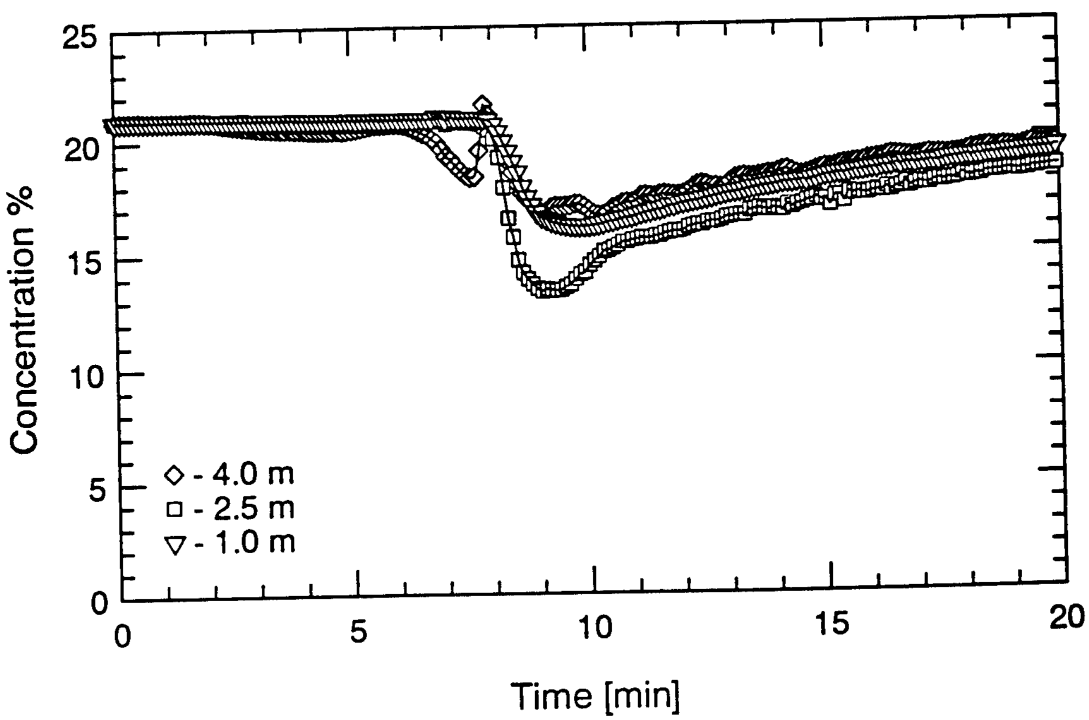

Pressure Measurements
TEST #31



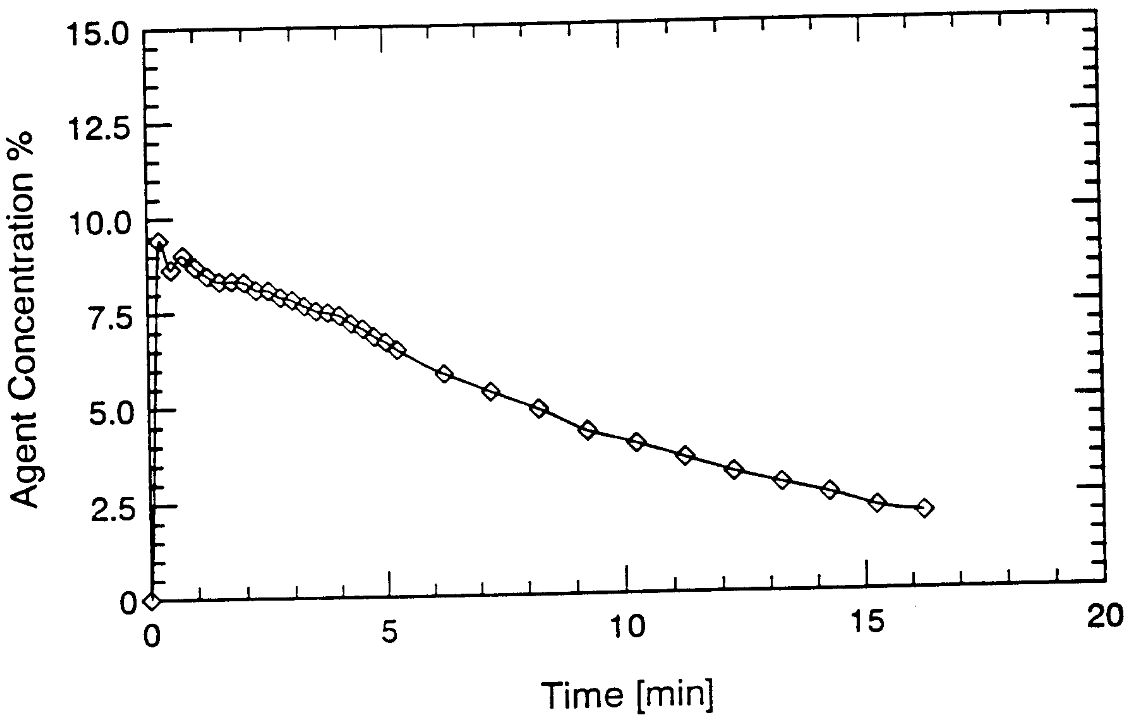



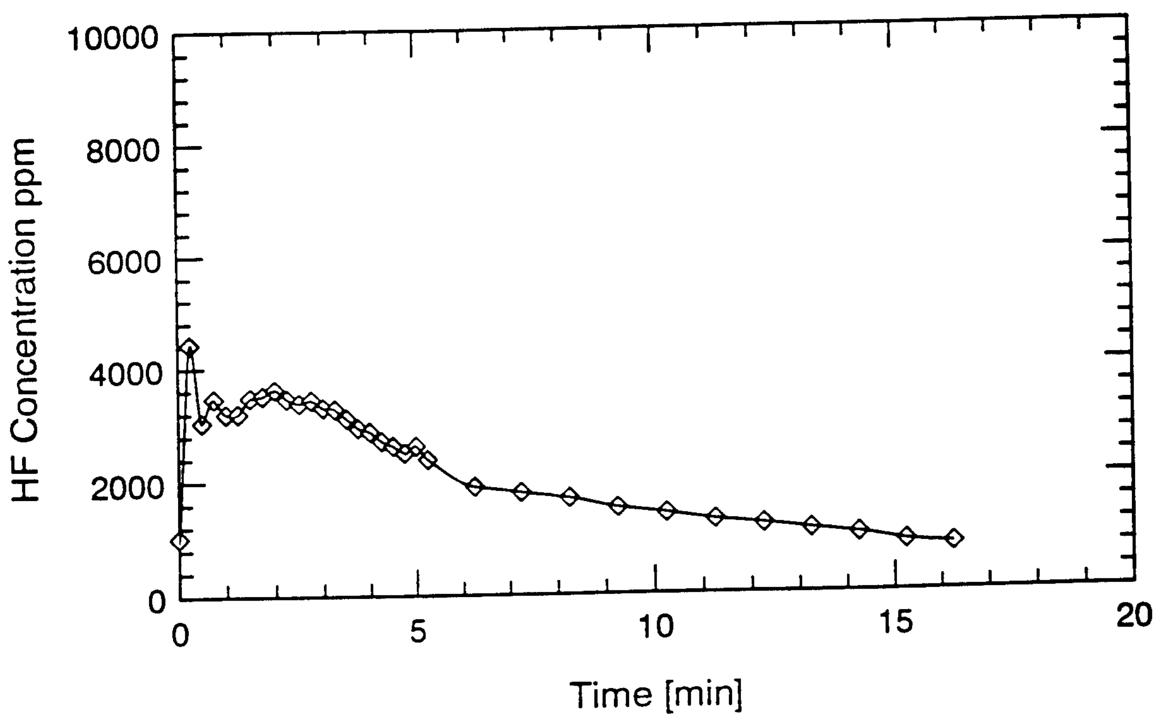

Compartment Temperatures
TEST #32



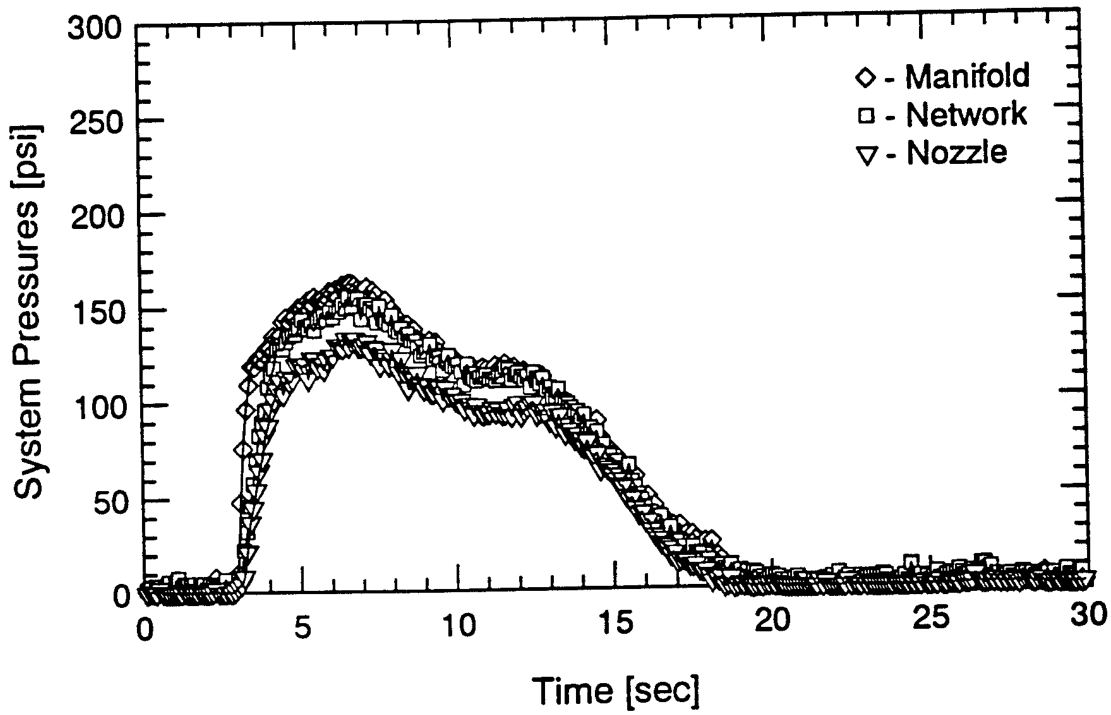



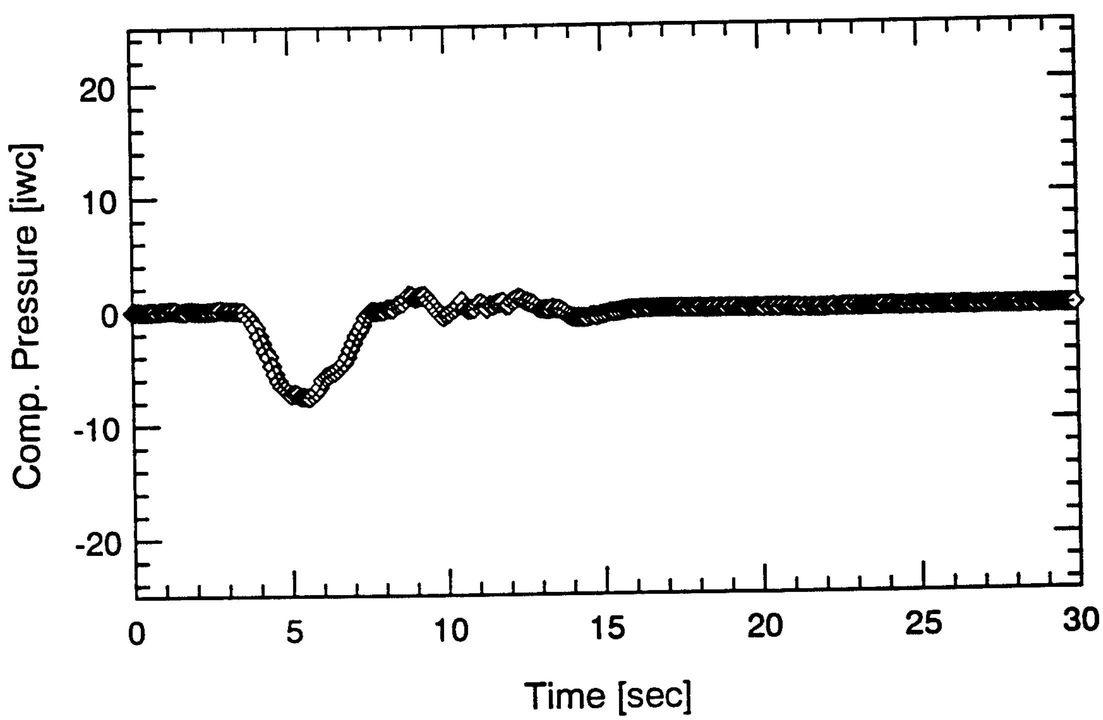

Oxygen Concentrations
TEST #32



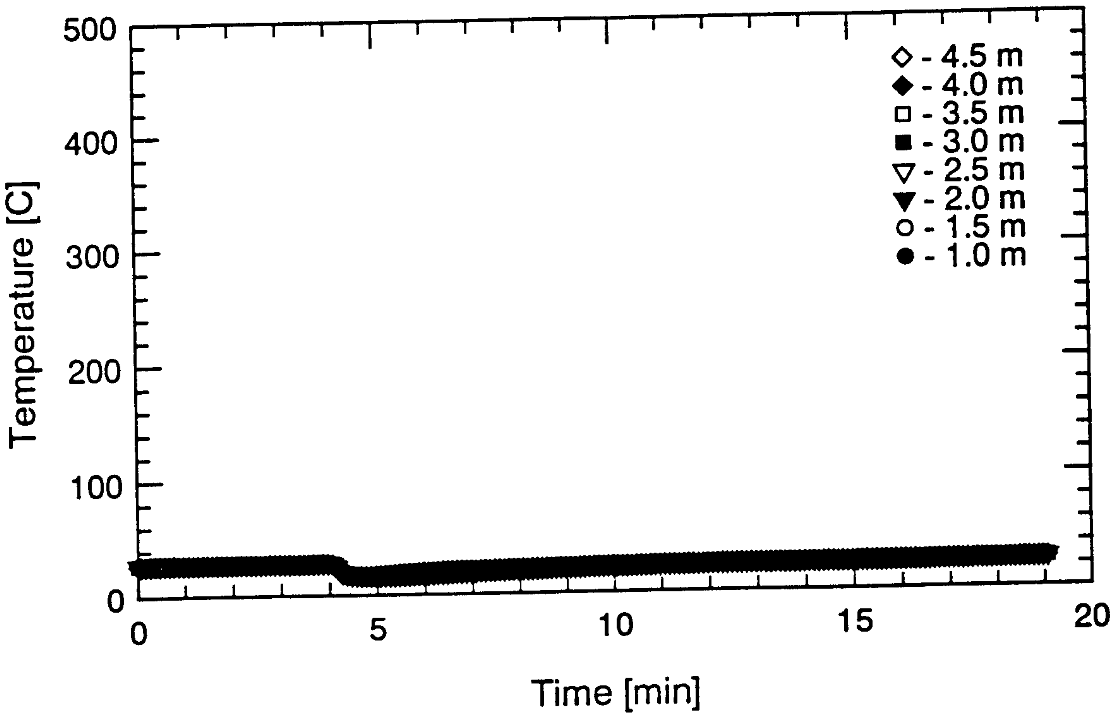



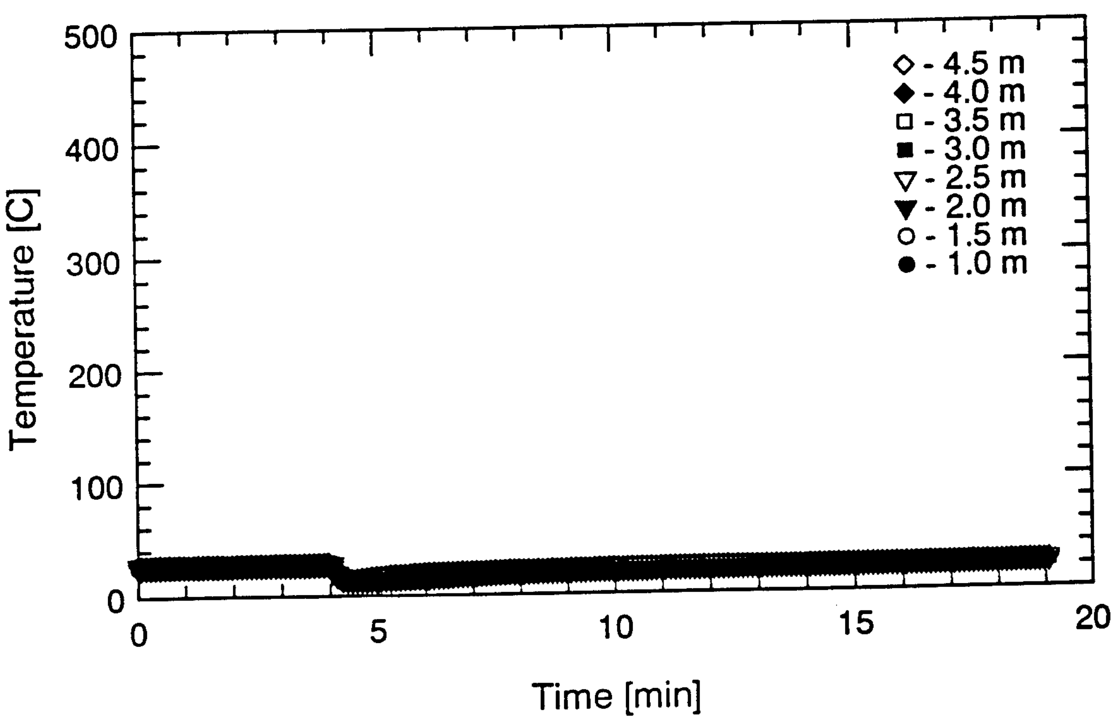

Agent and HF Concentrations
TEST #32



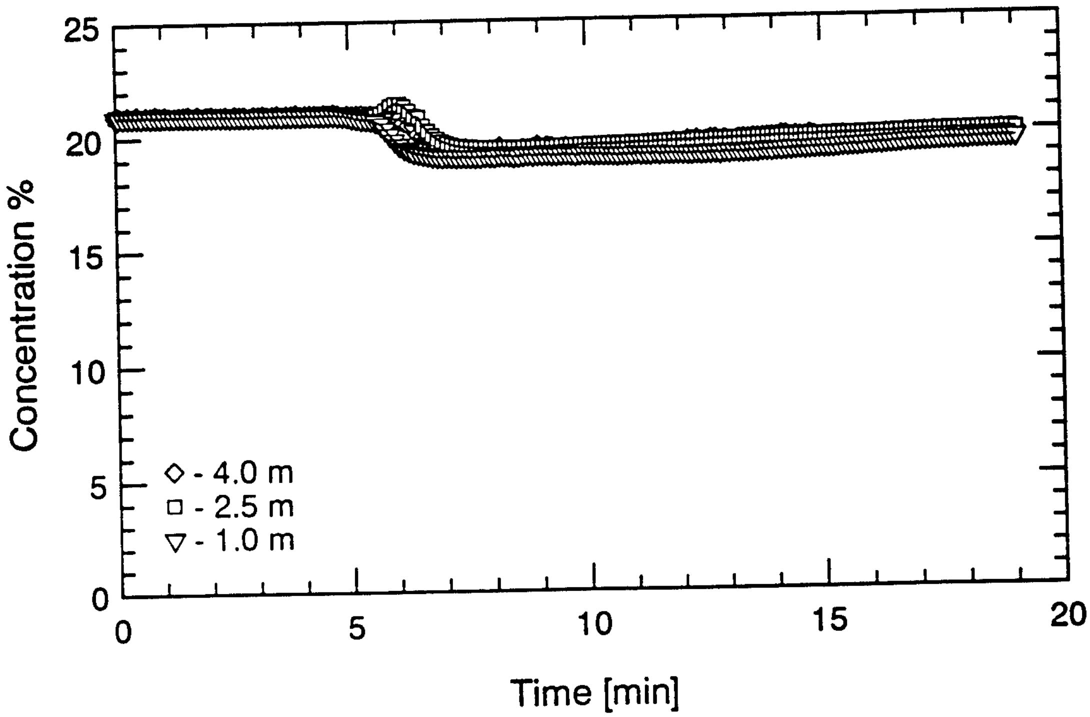



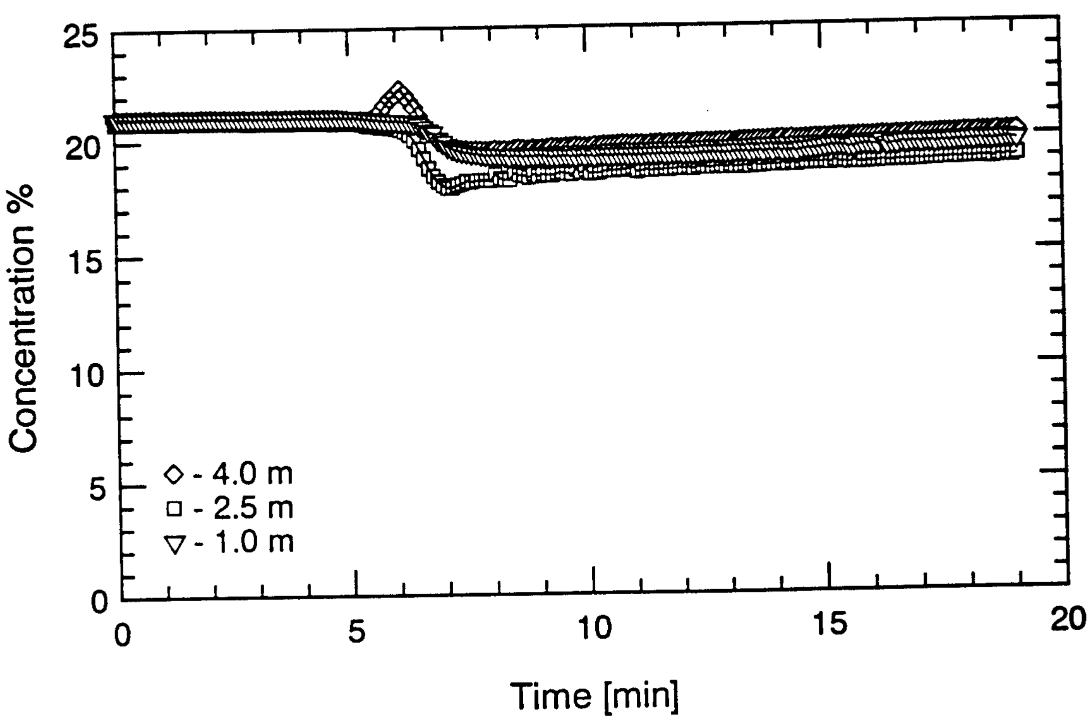

Pressure Measurements
TEST #32



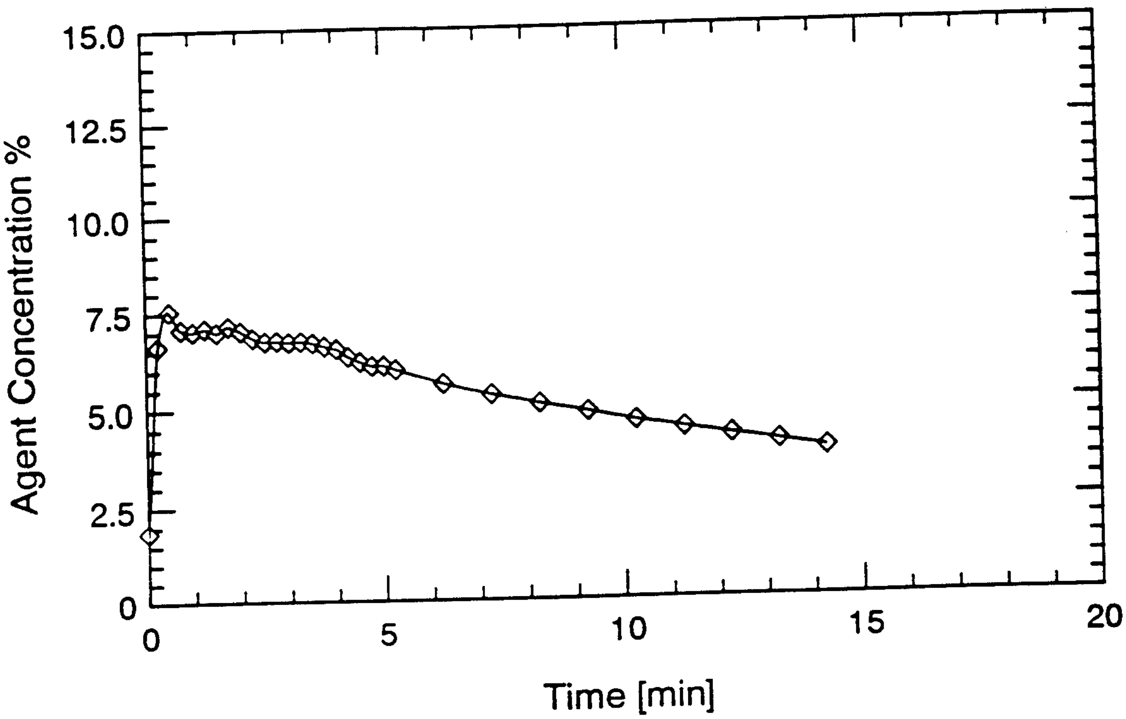



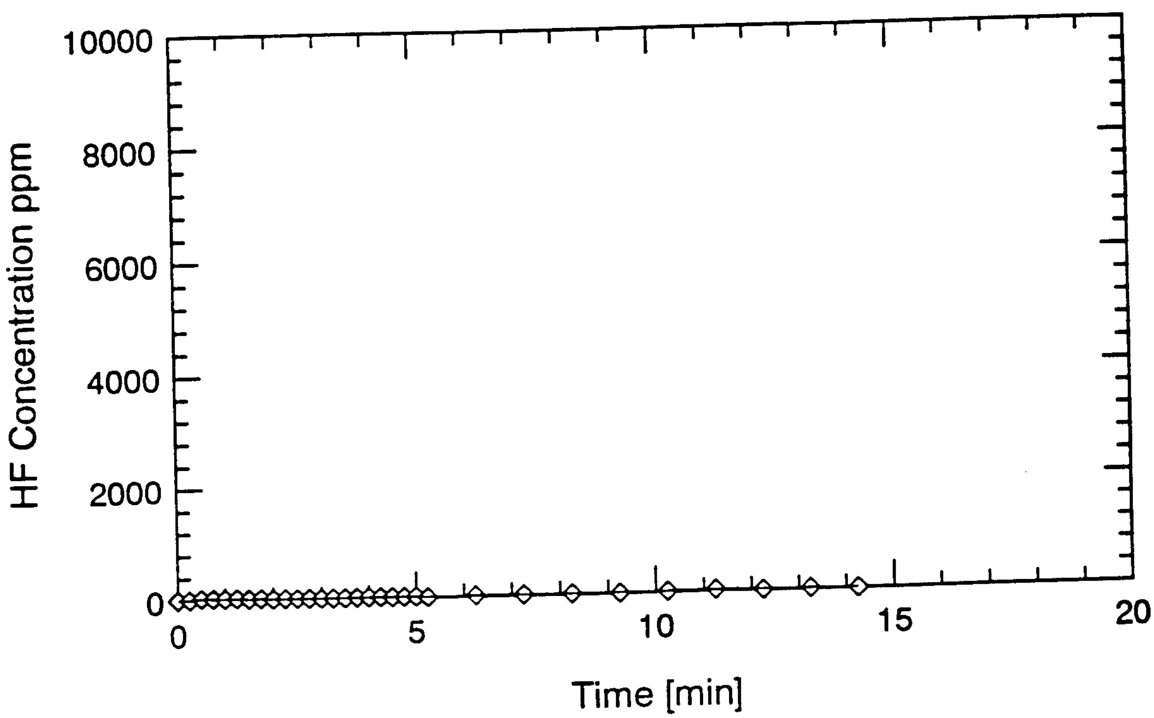

Compartment Temperatures
TEST #33



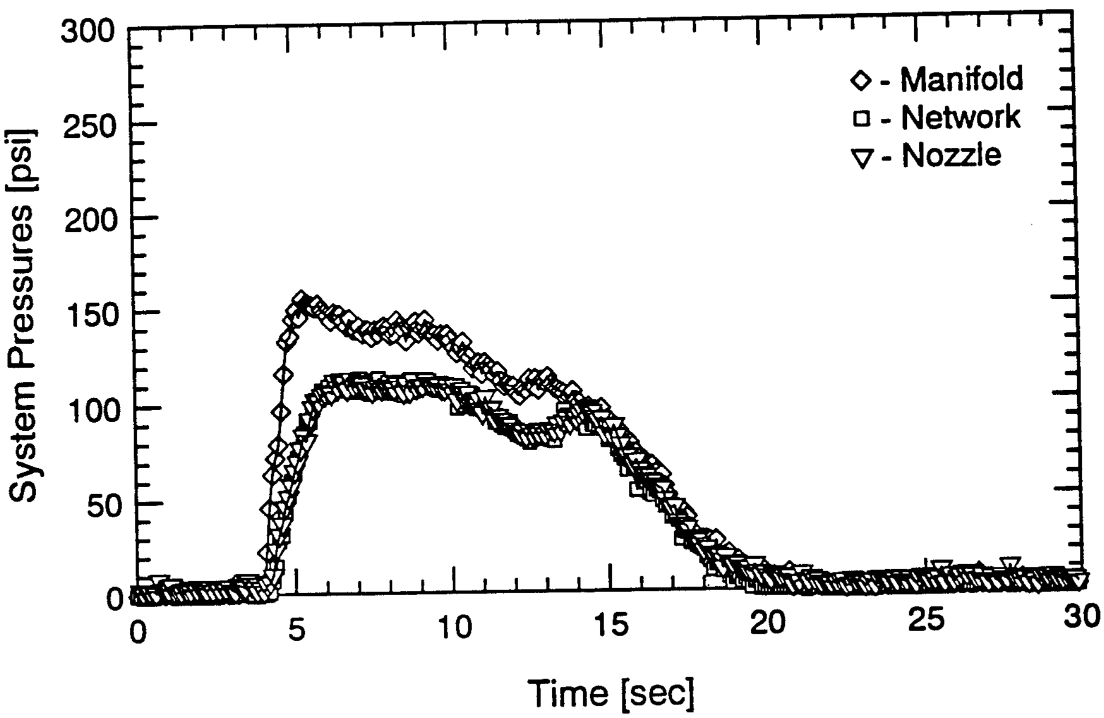



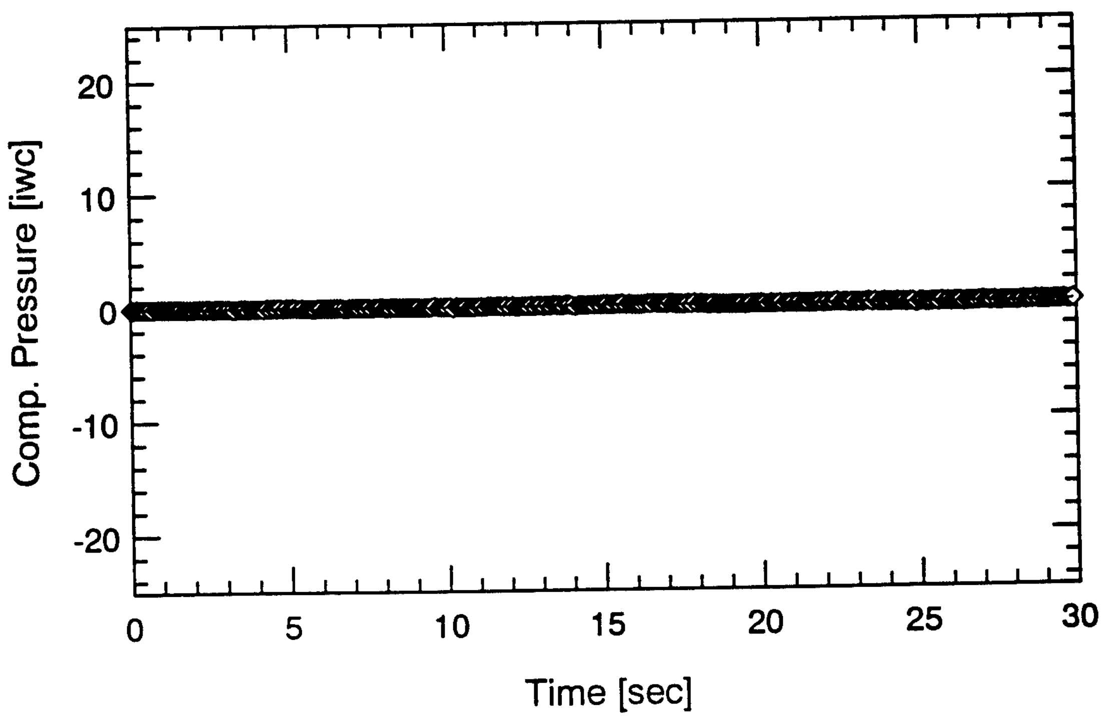

Oxygen Concentrations
TEST #33



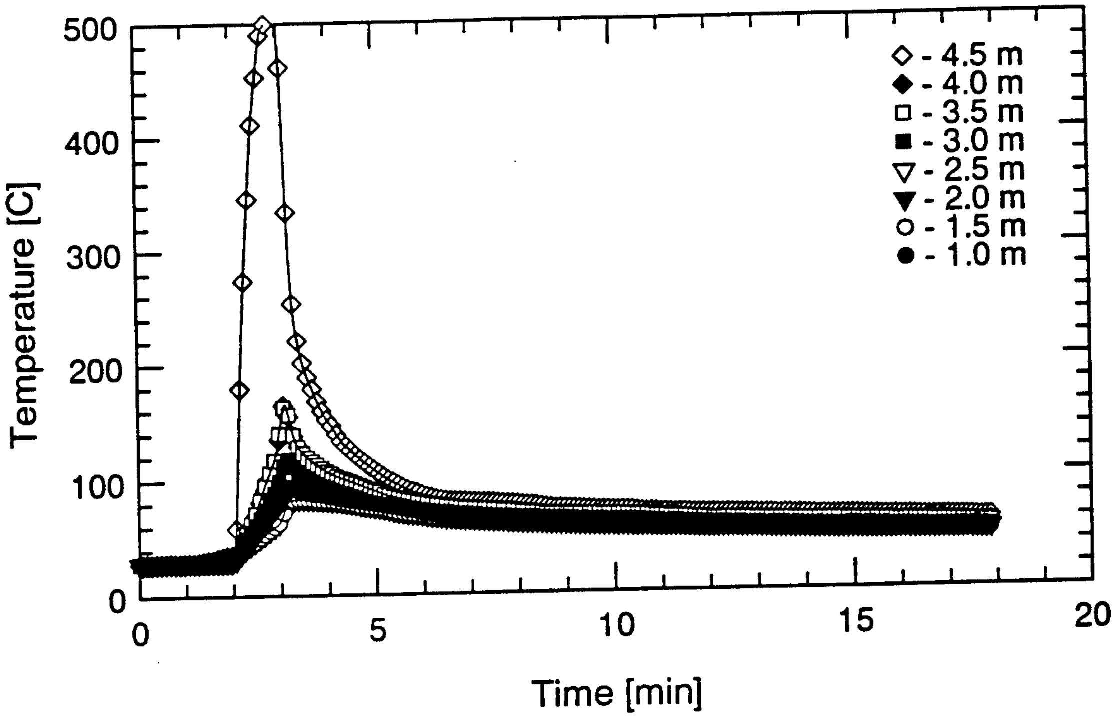



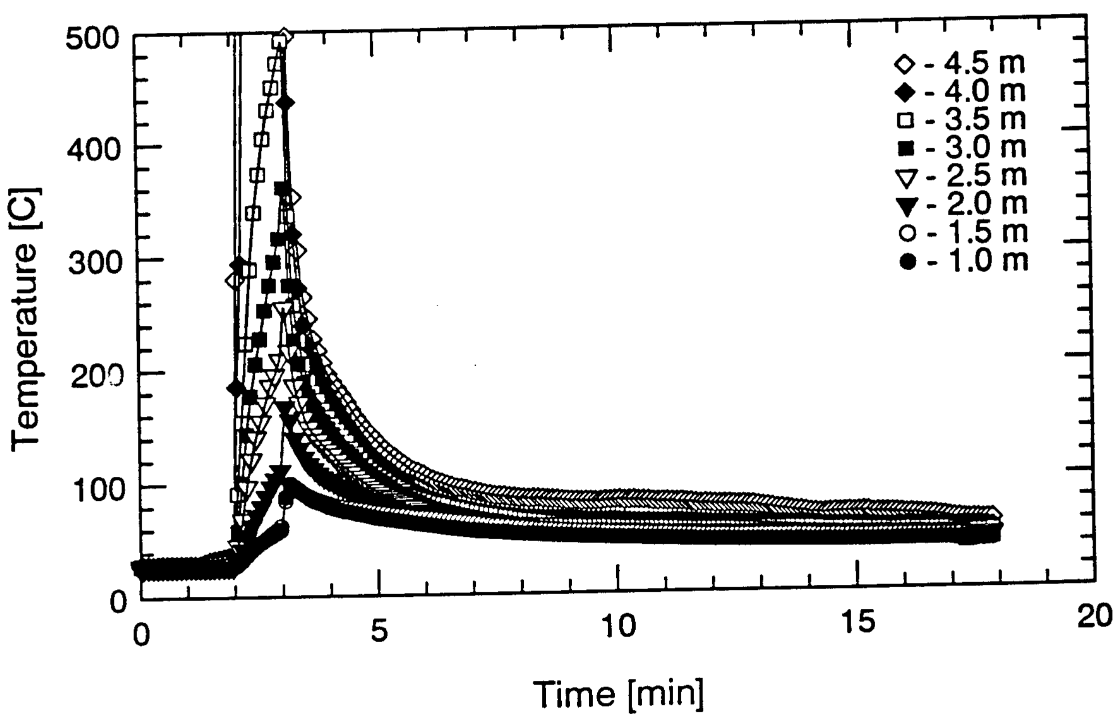

Agent and HF Concentrations
TEST #33



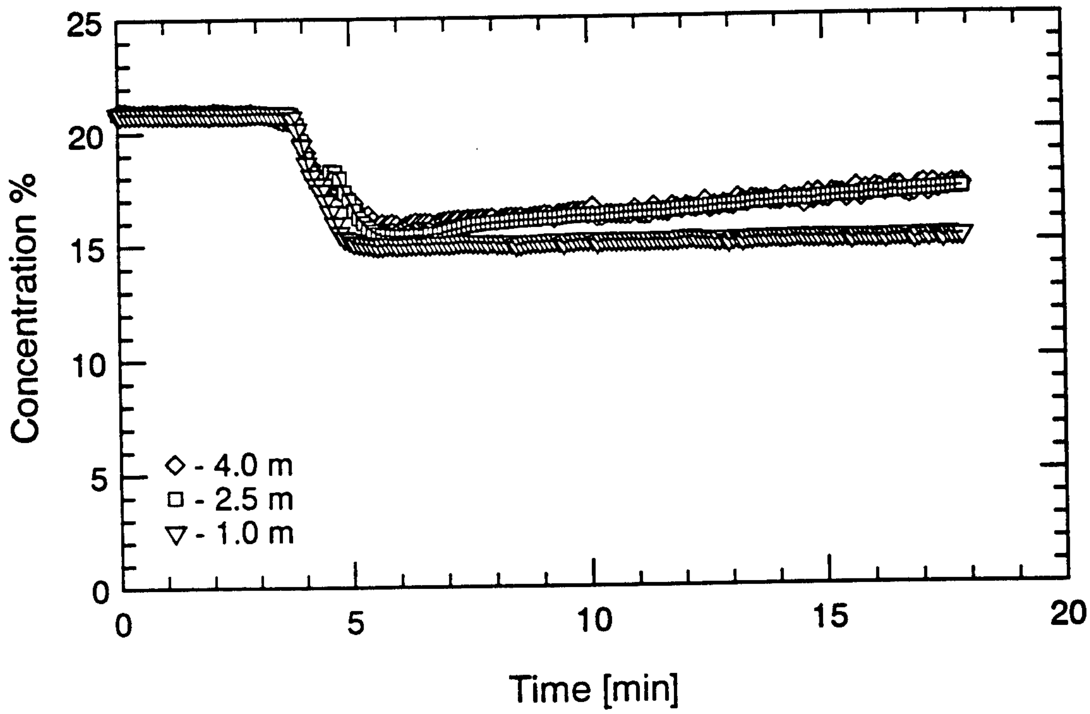



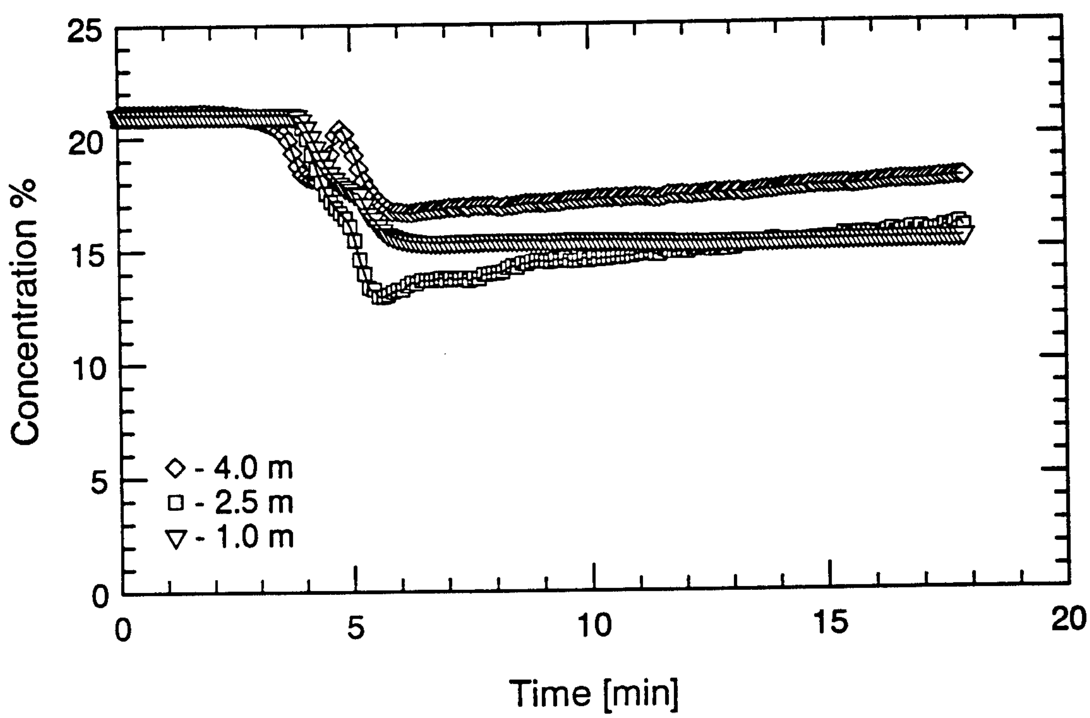

Pressure Measurements
TEST #33



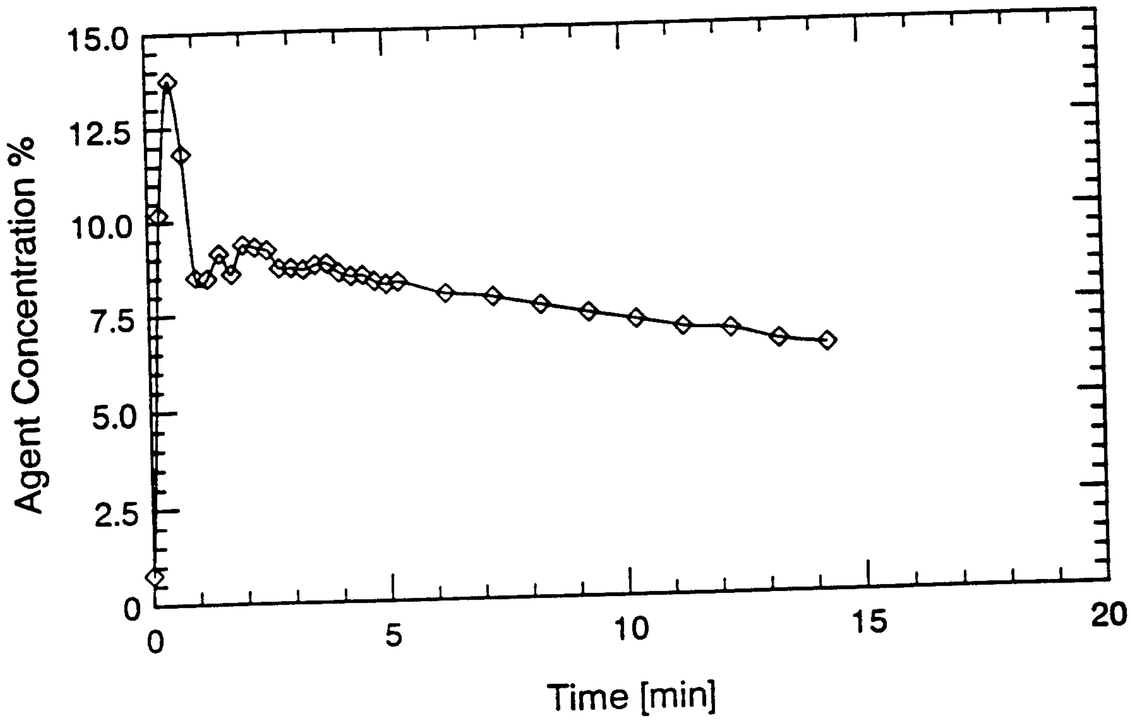



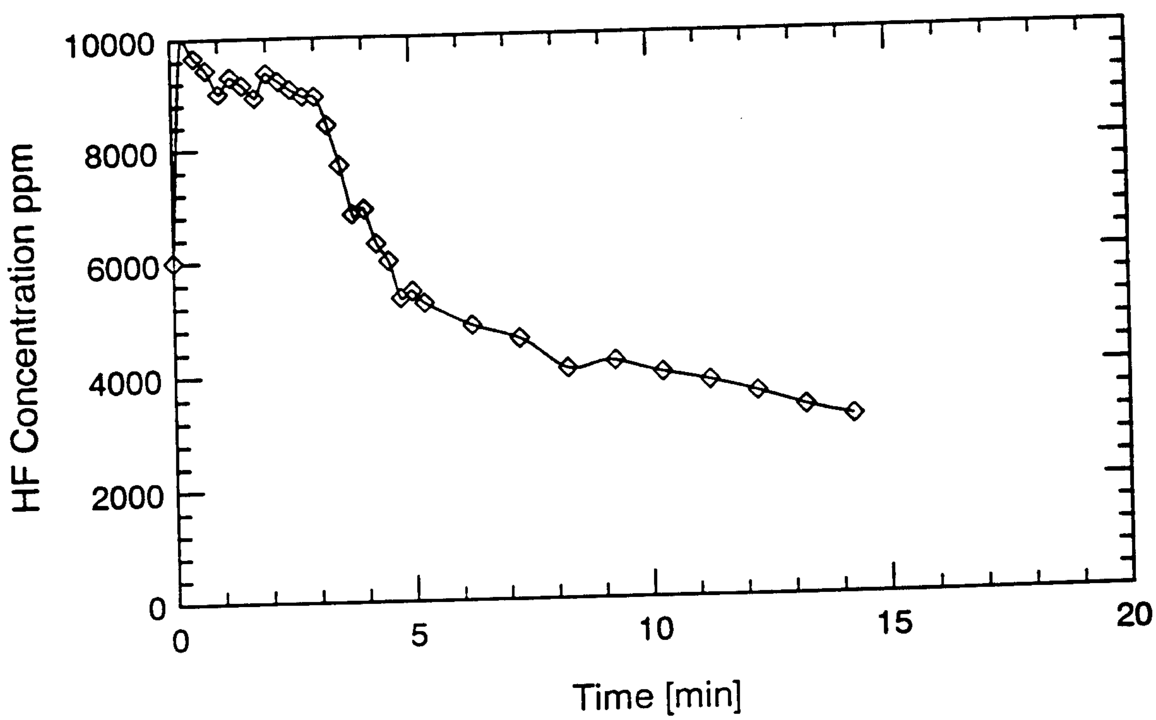

Compartment Temperatures
TEST #34



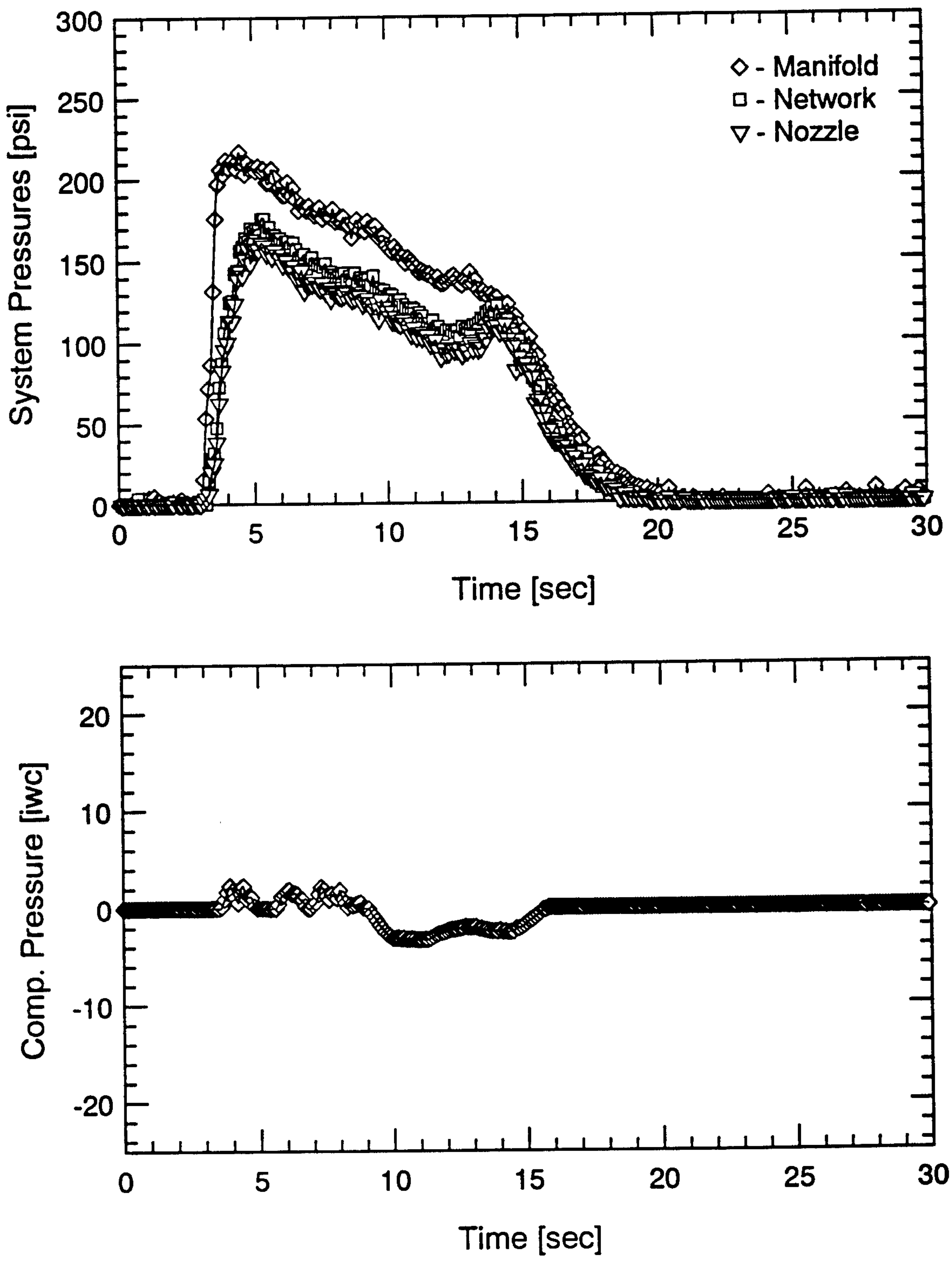




Oxygen Concentrations
TEST #34

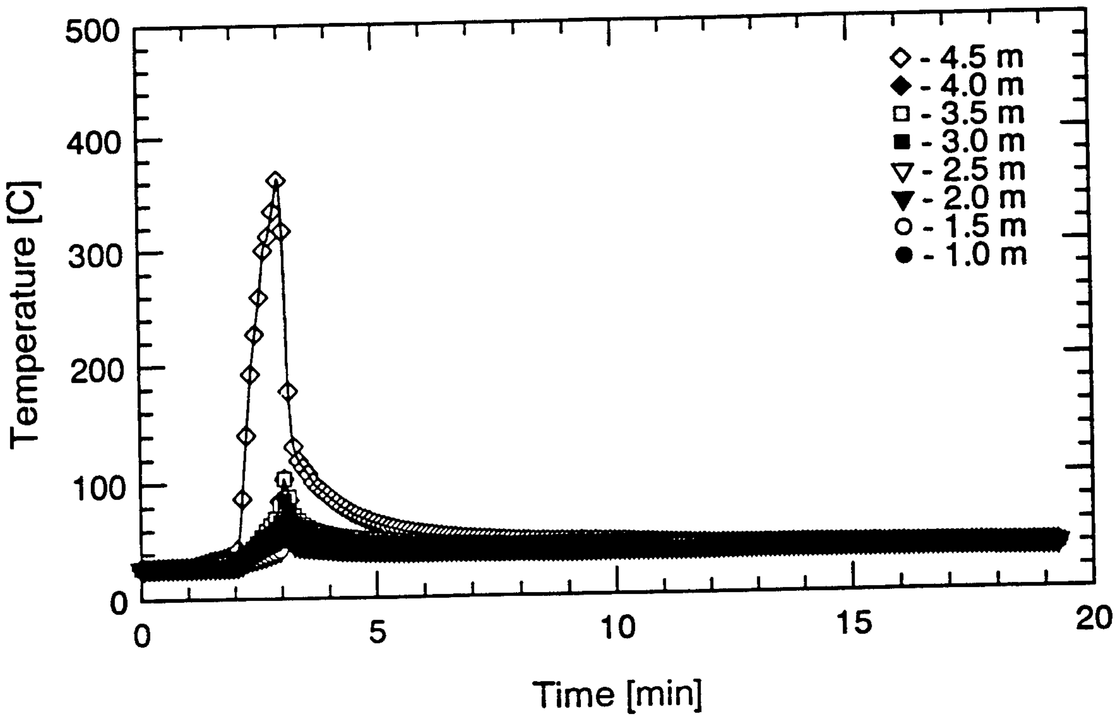


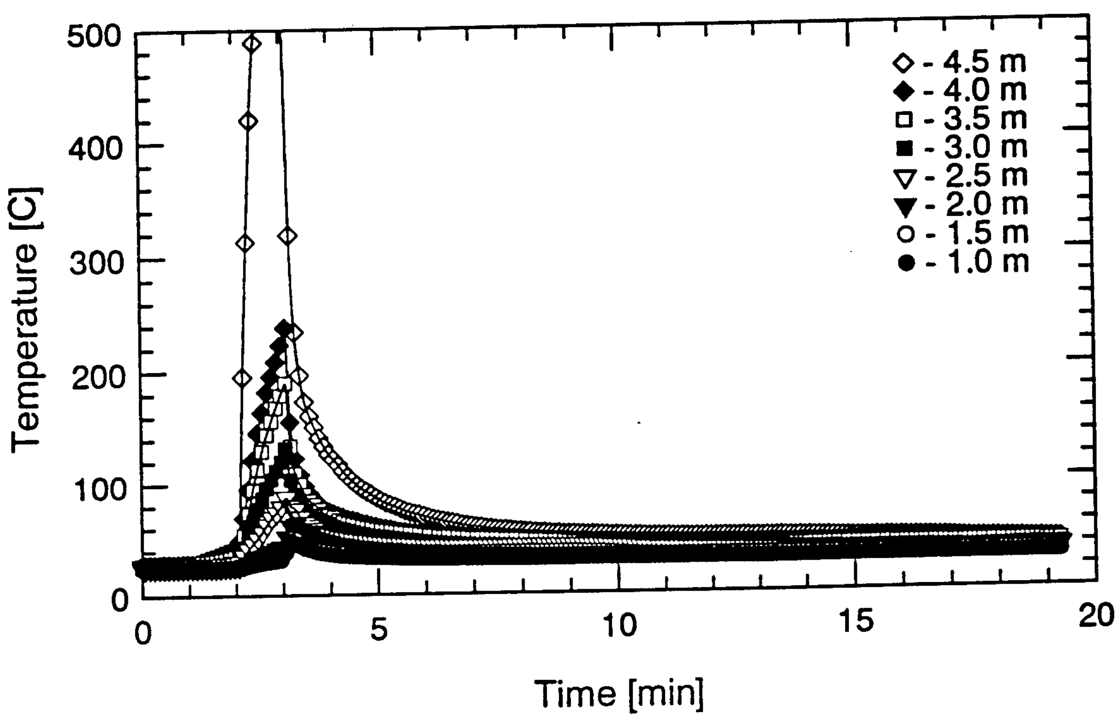




Agent and HF Concentrations
TEST #34

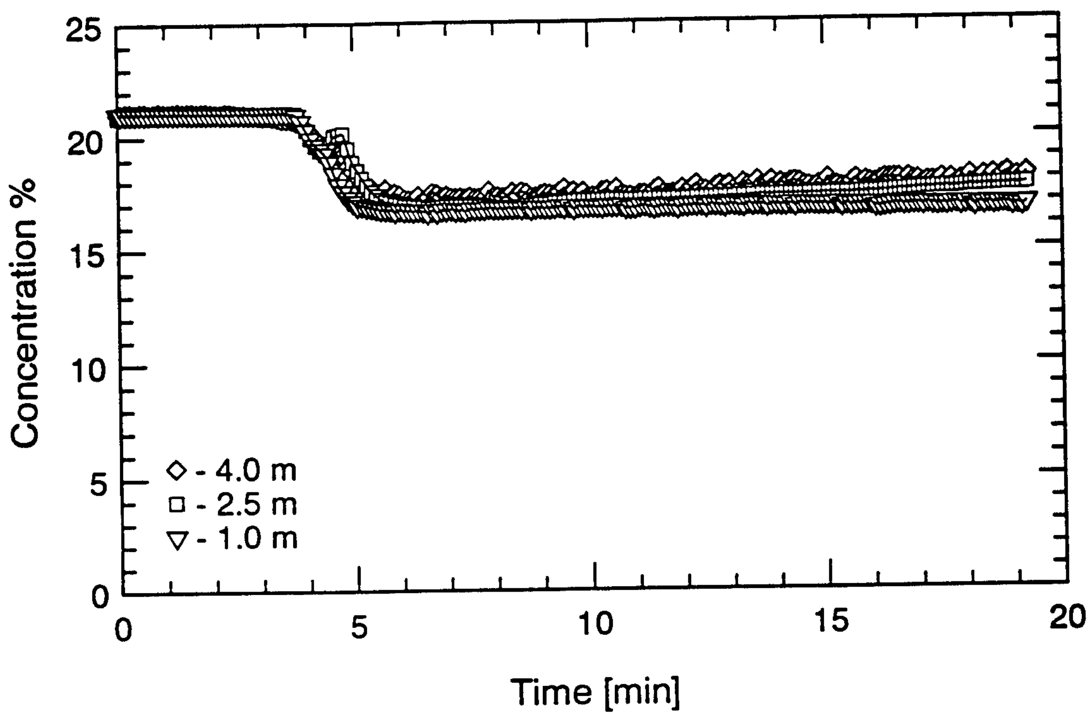


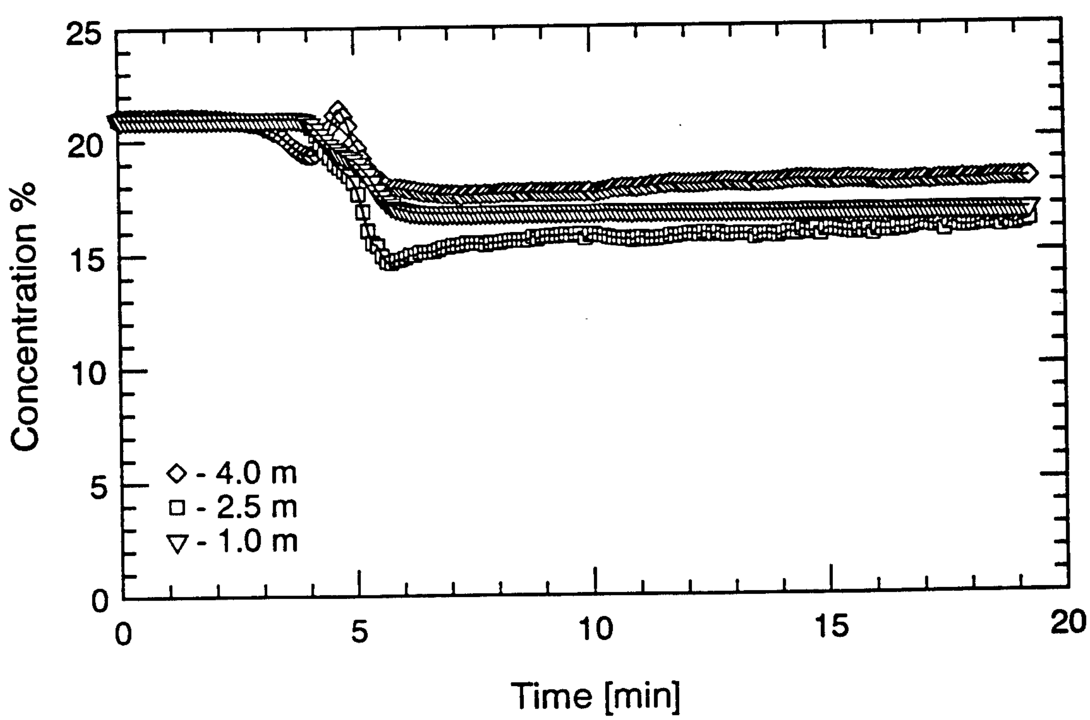

Pressure Measurements
TEST #34



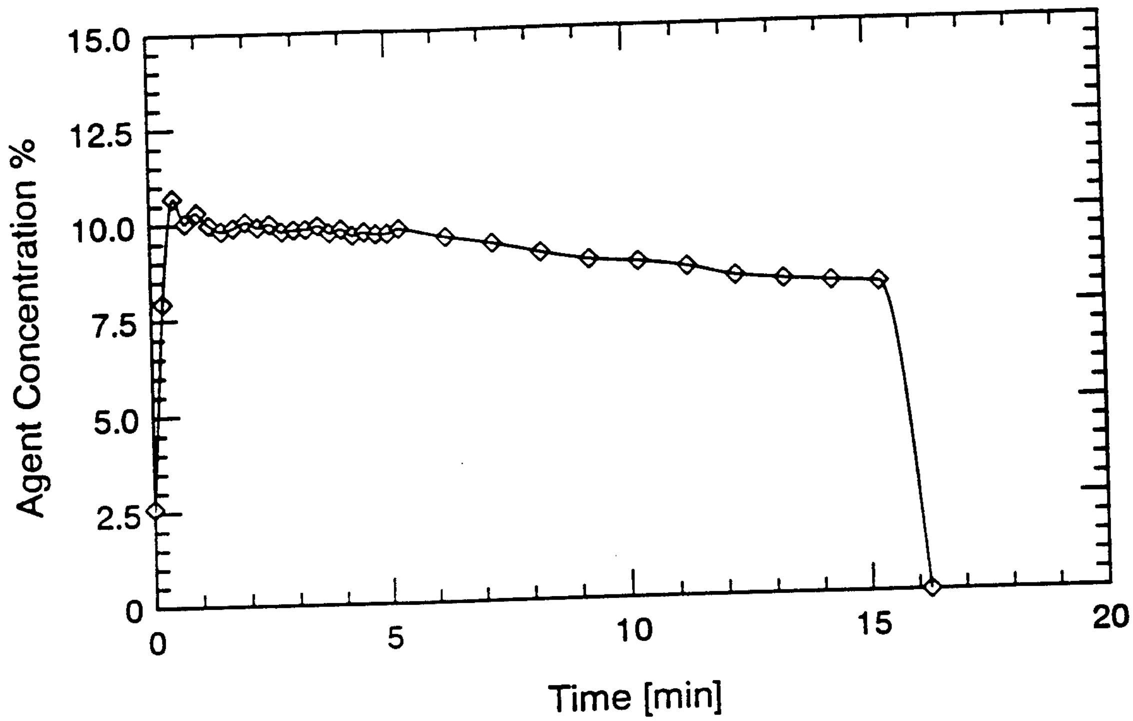



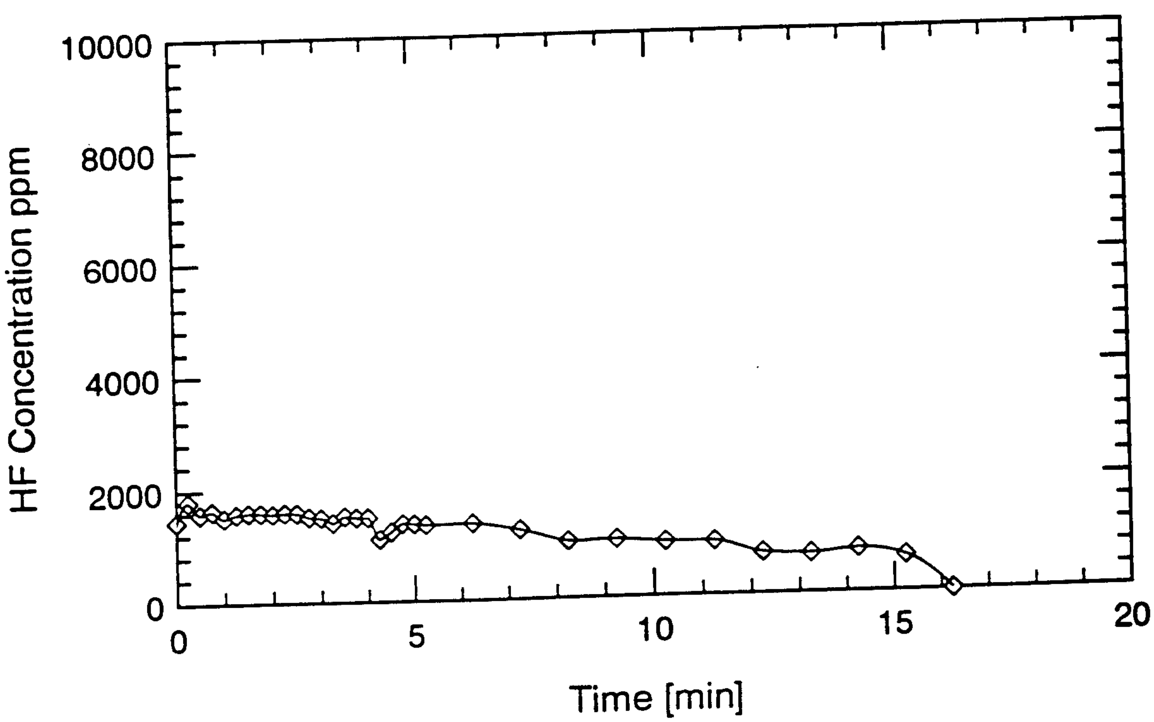

Compartment Temperatures
TEST #35



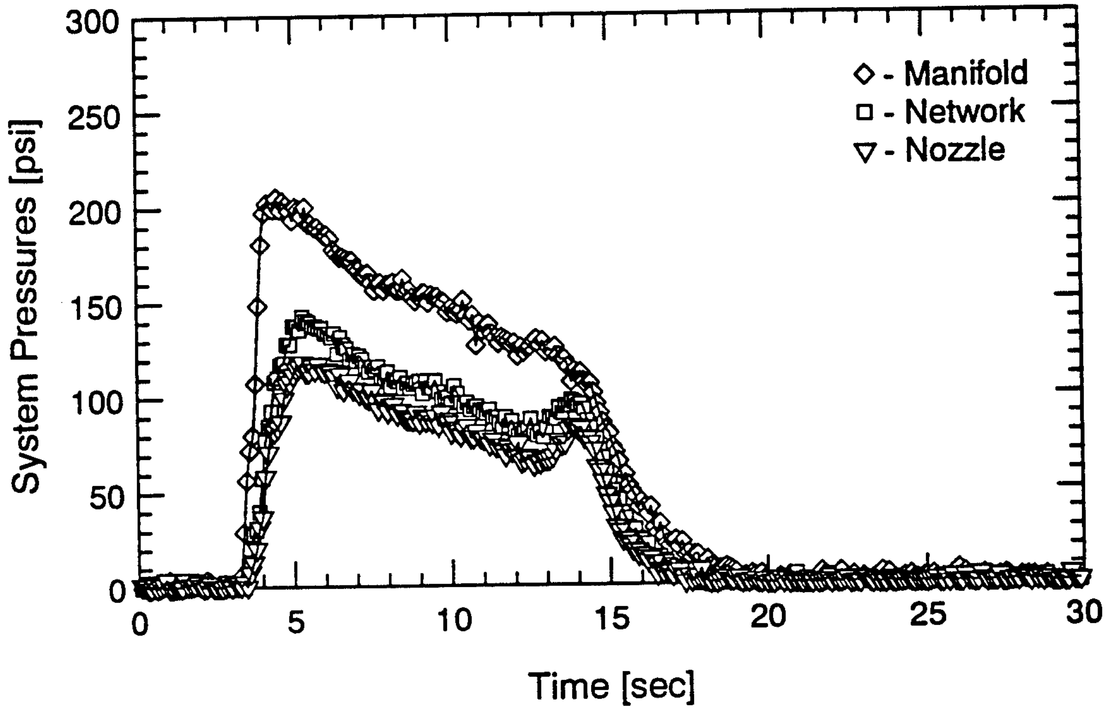



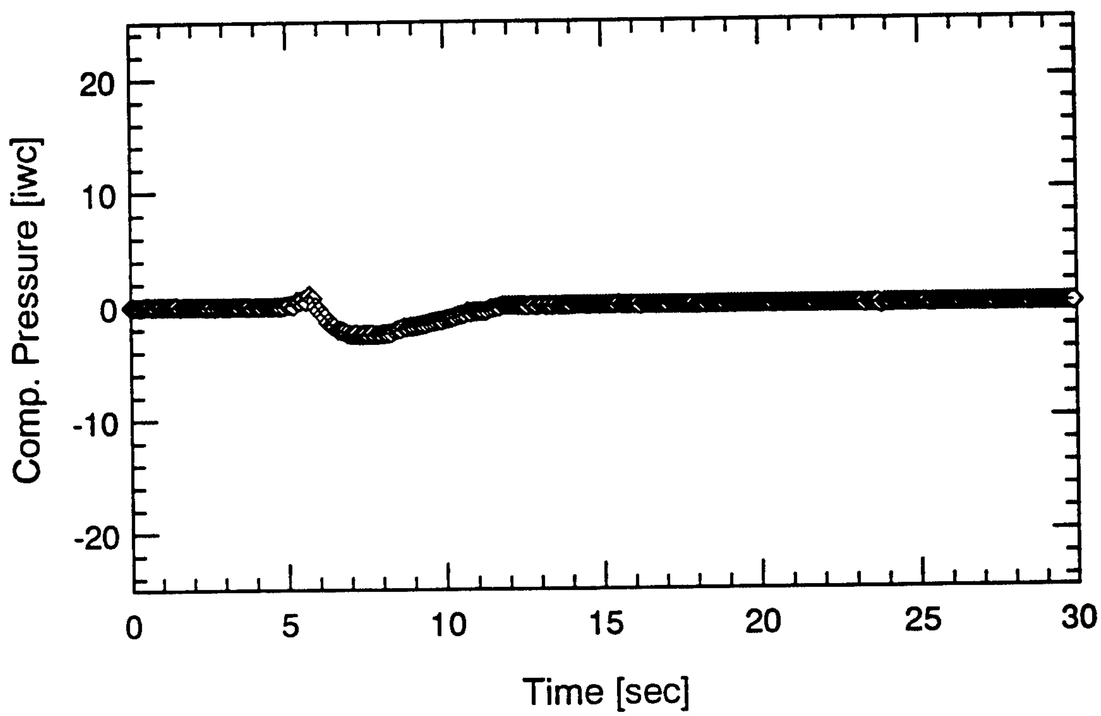

Oxygen Concentrations
TEST #35



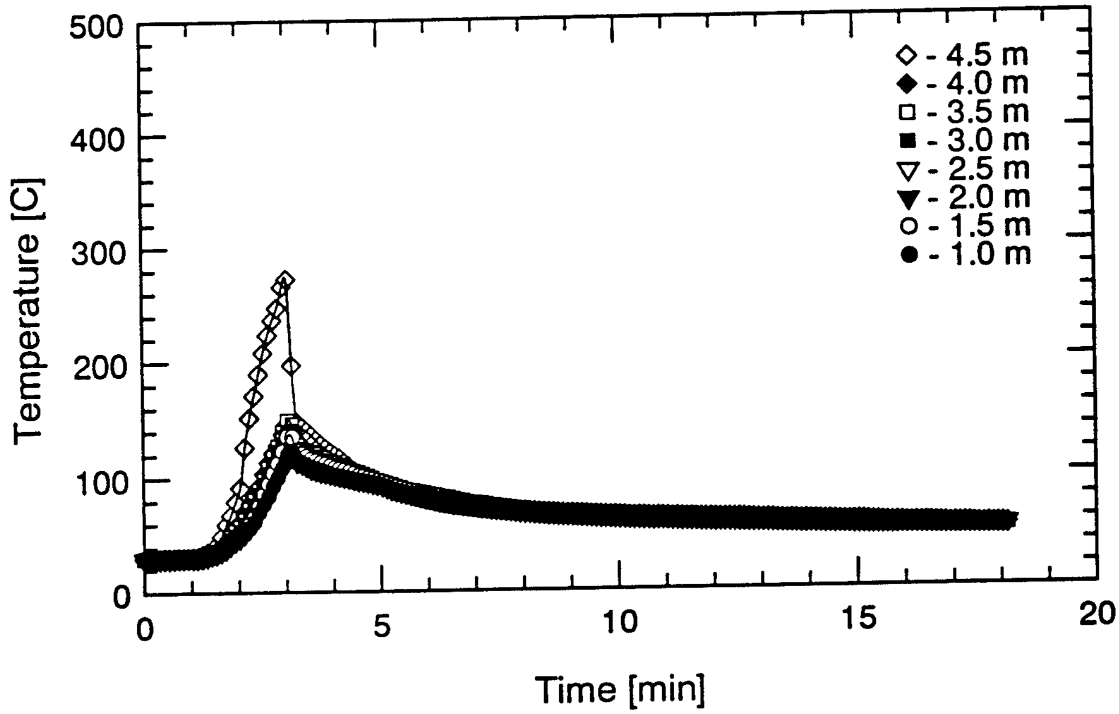



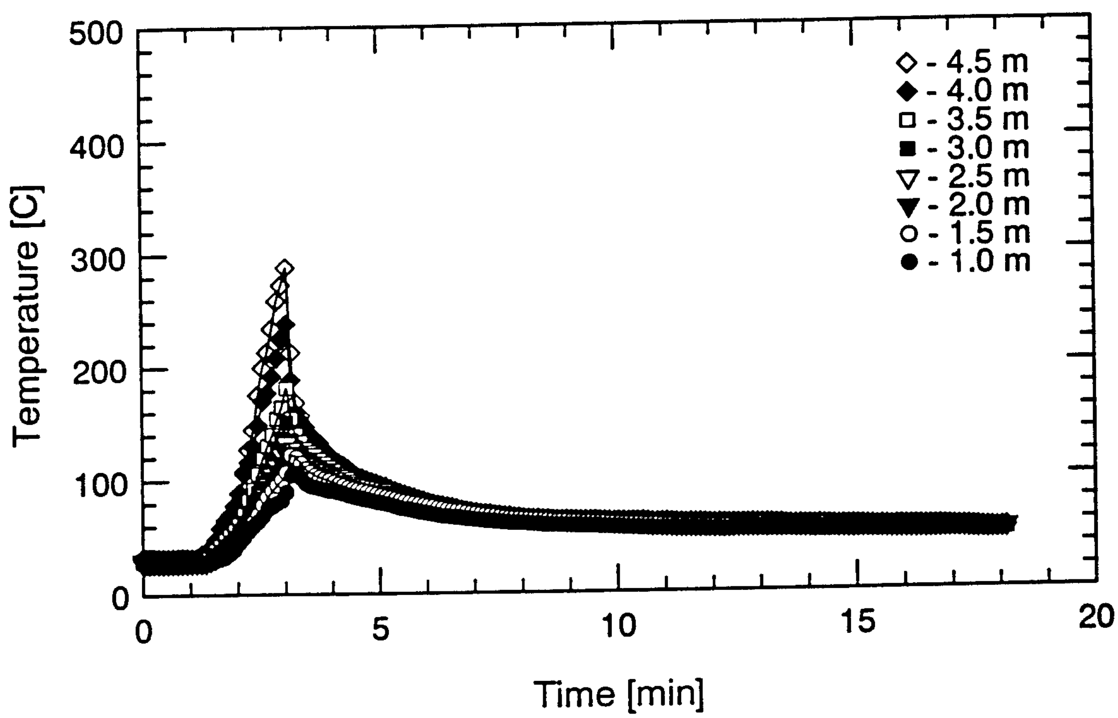

Agent and HF Concentrations
TEST #35



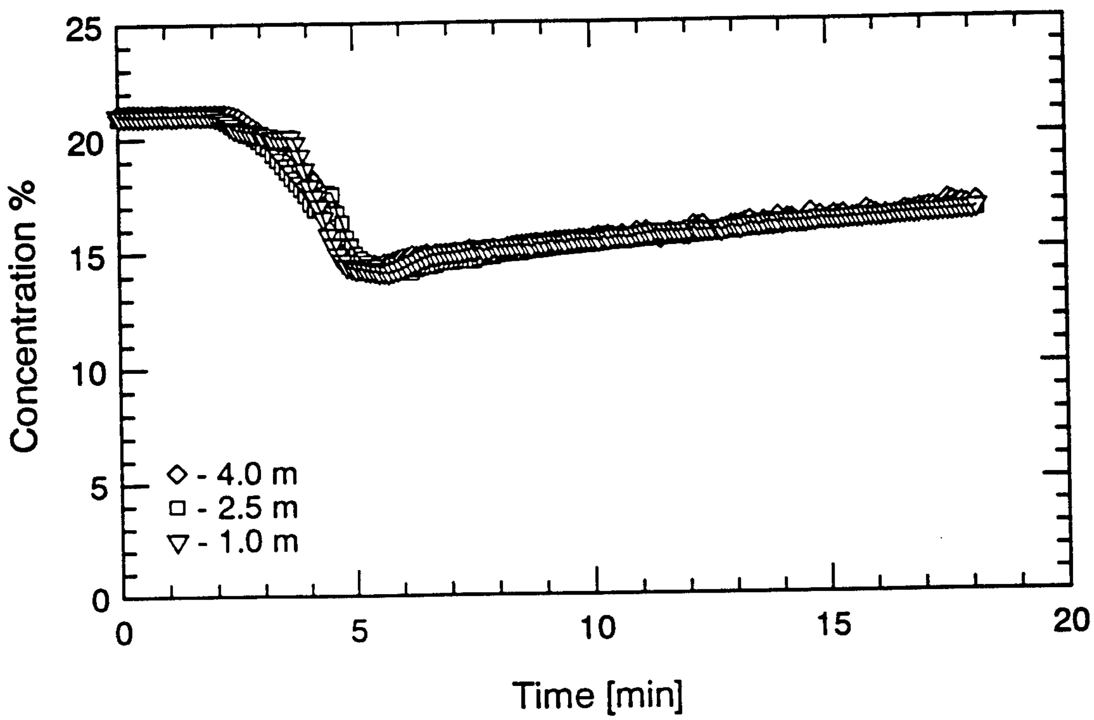



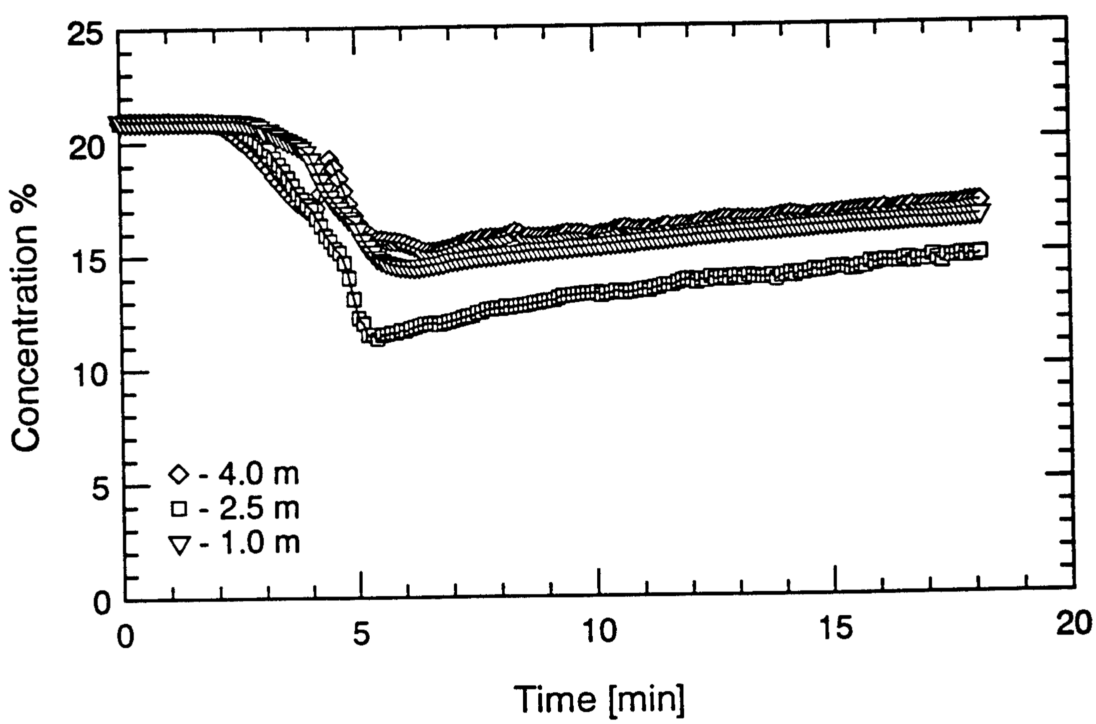

Pressure Measurements
TEST #35



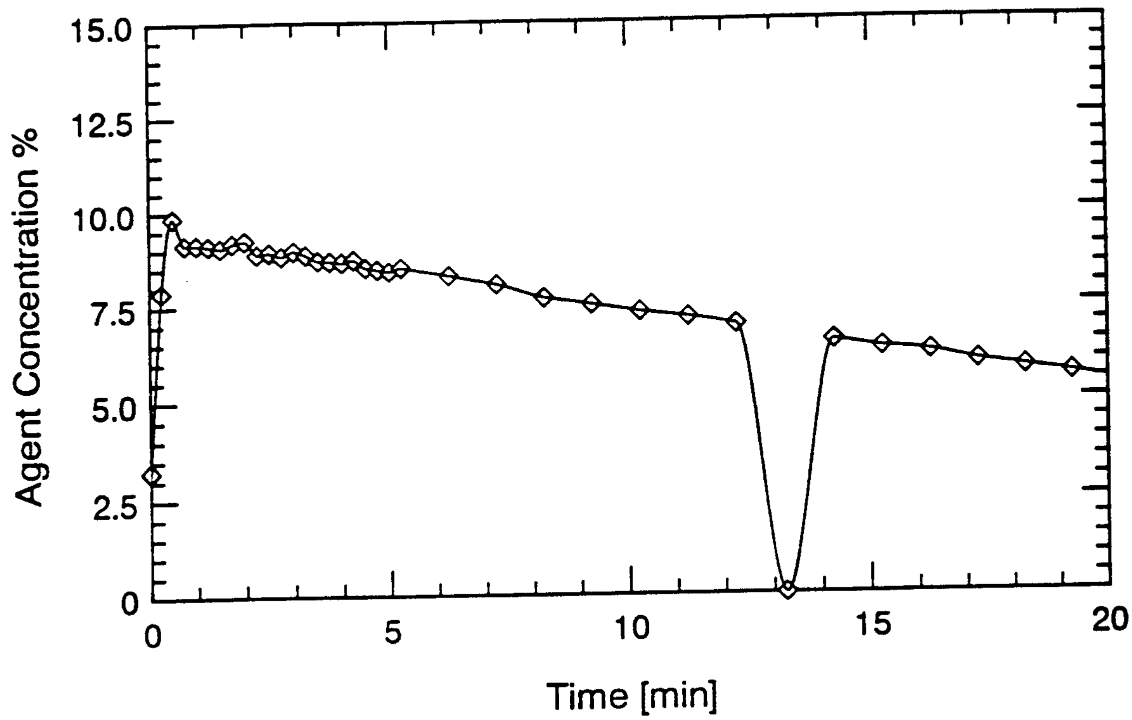



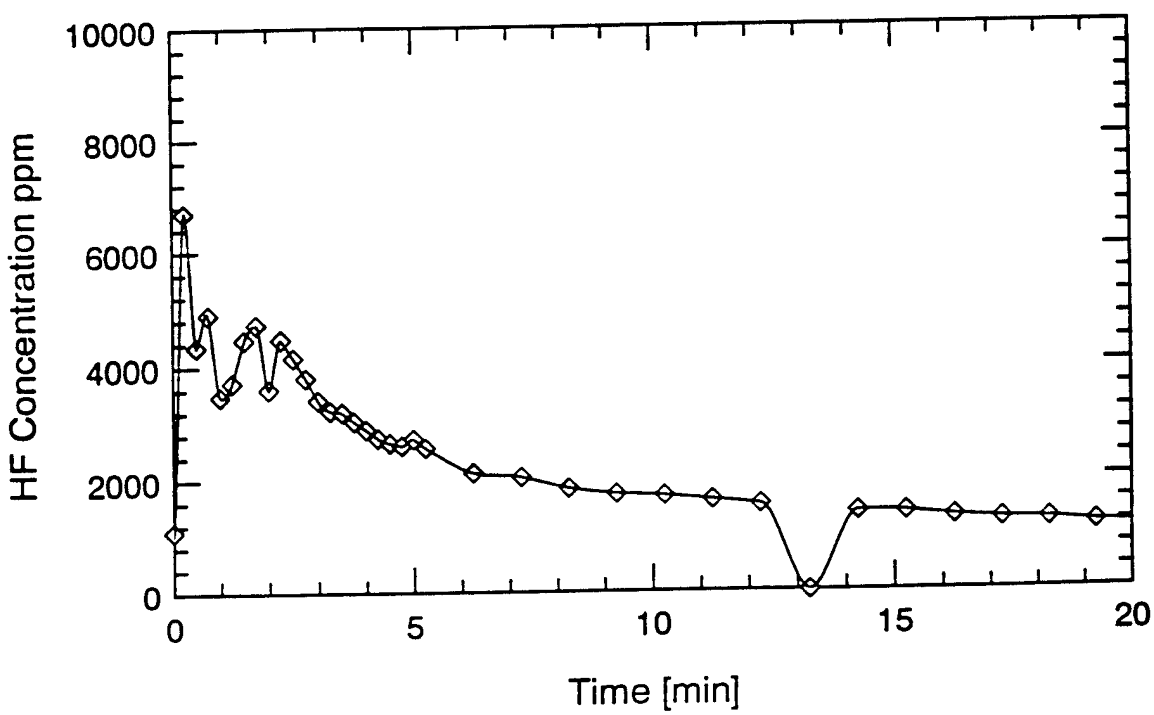

Compartment Temperatures
TEST #36



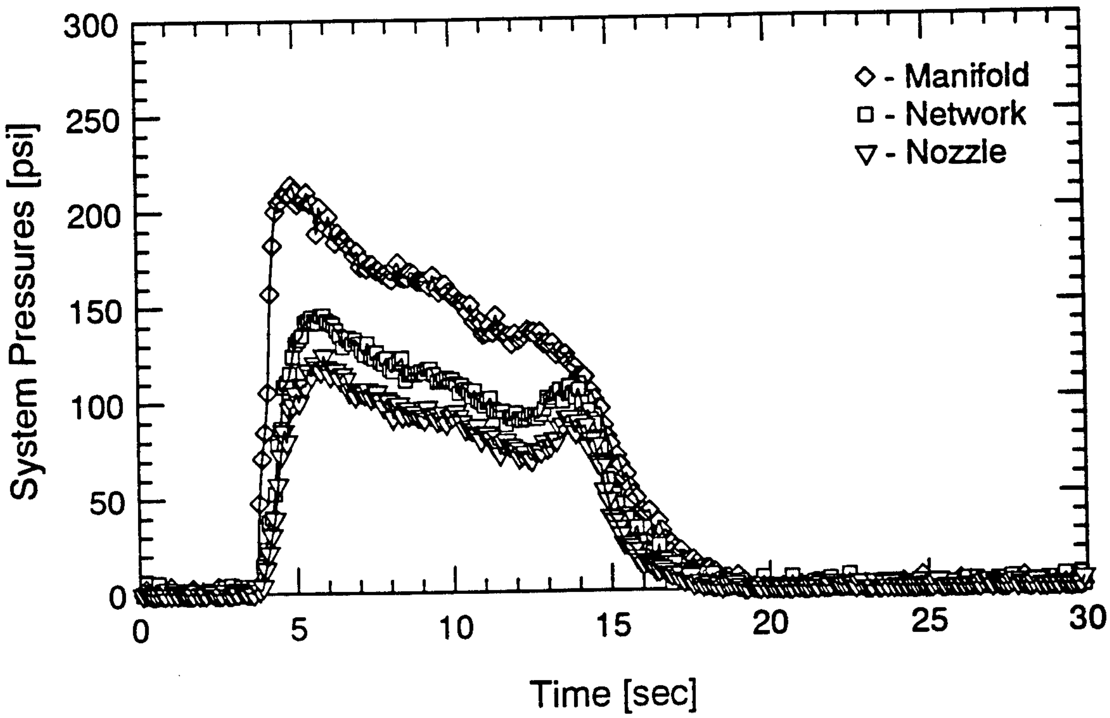



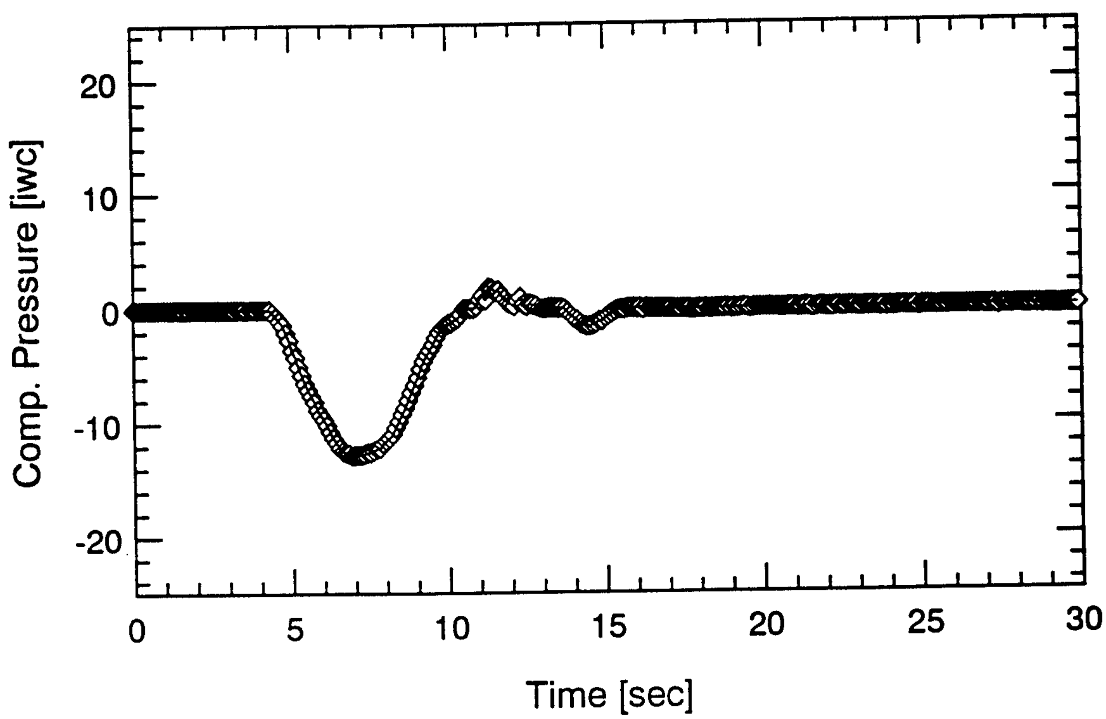

Oxygen Concentrations
TEST #36



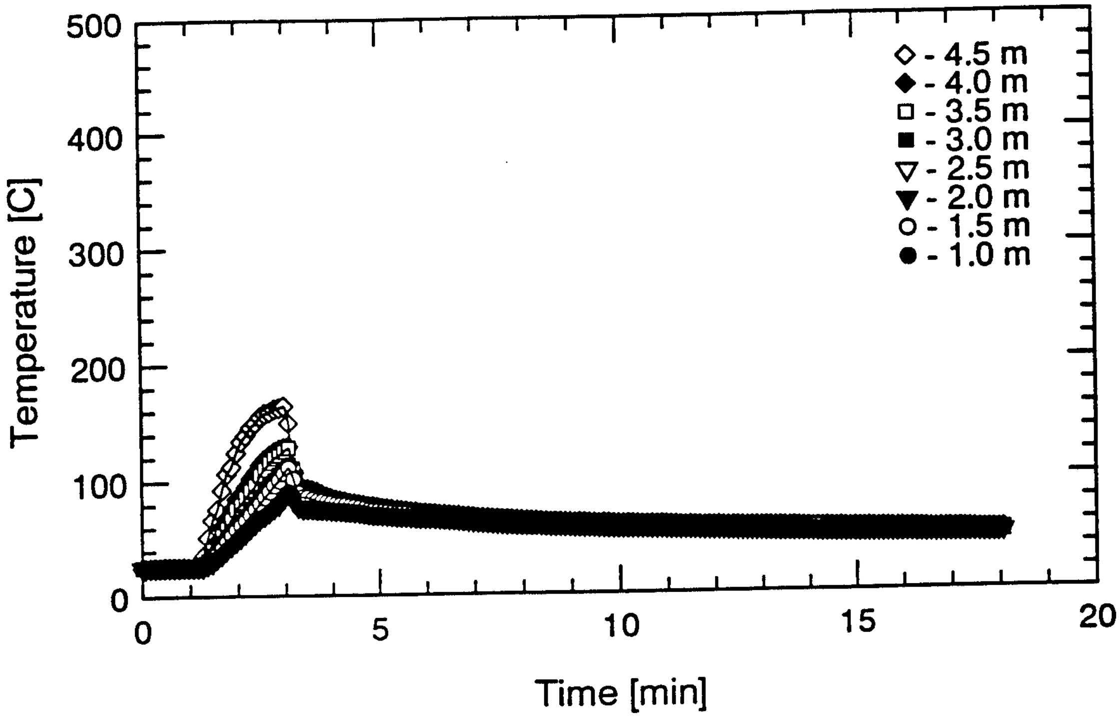



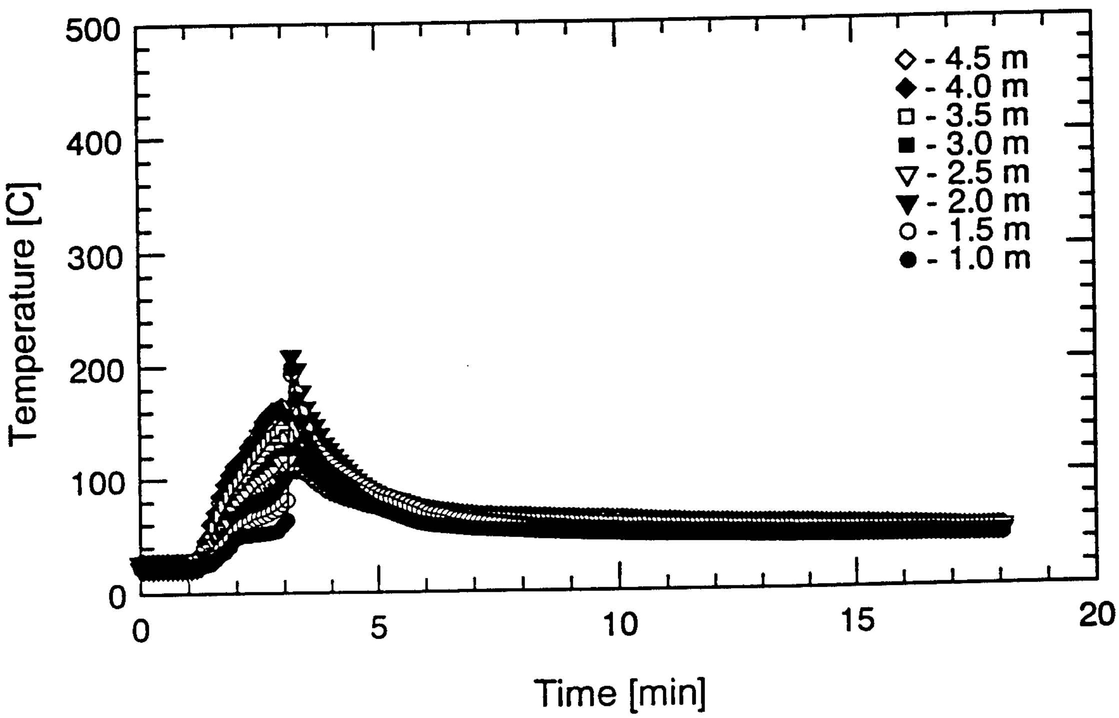

Agent and HF Concentrations
TEST #36



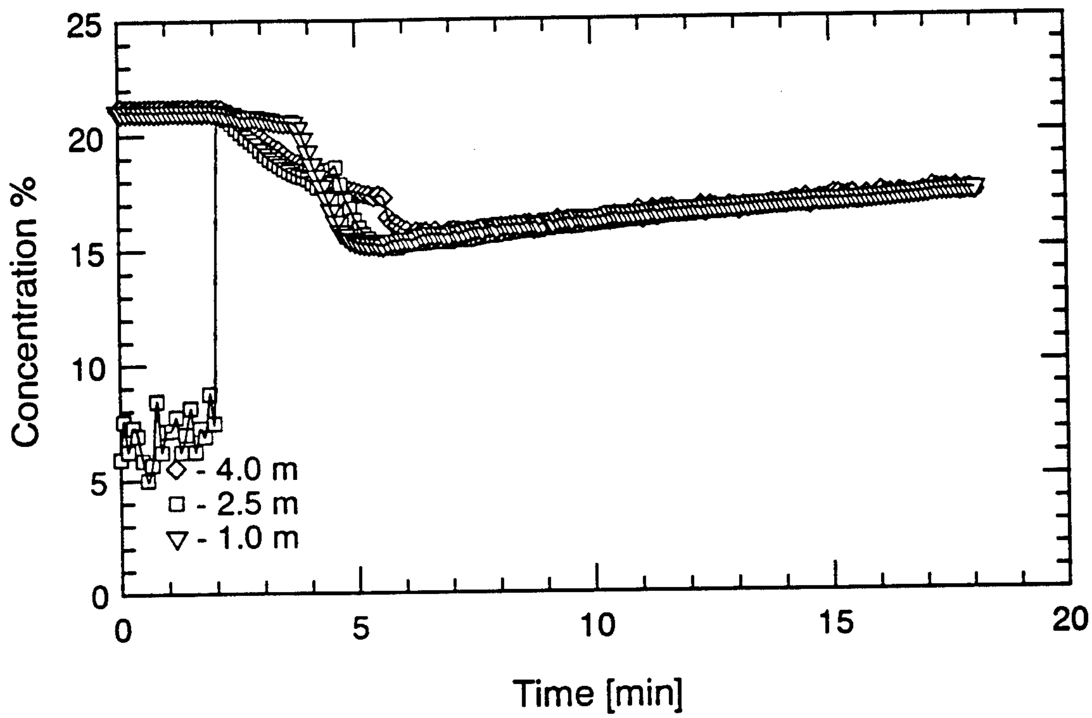



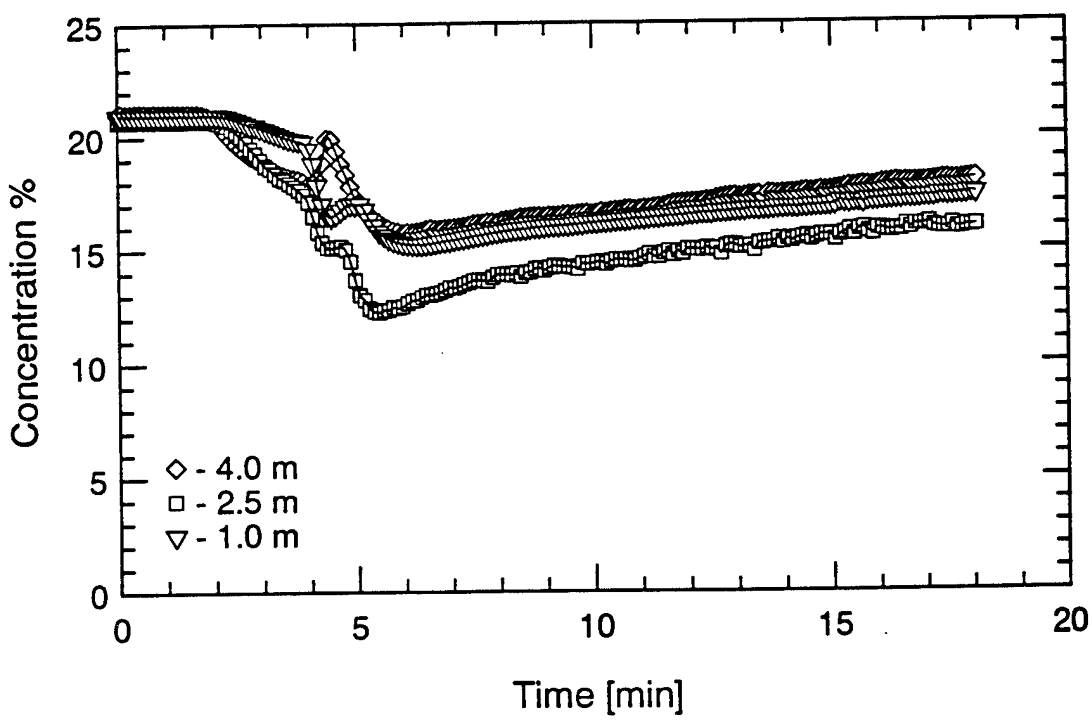

Pressure Measurements
TEST #36



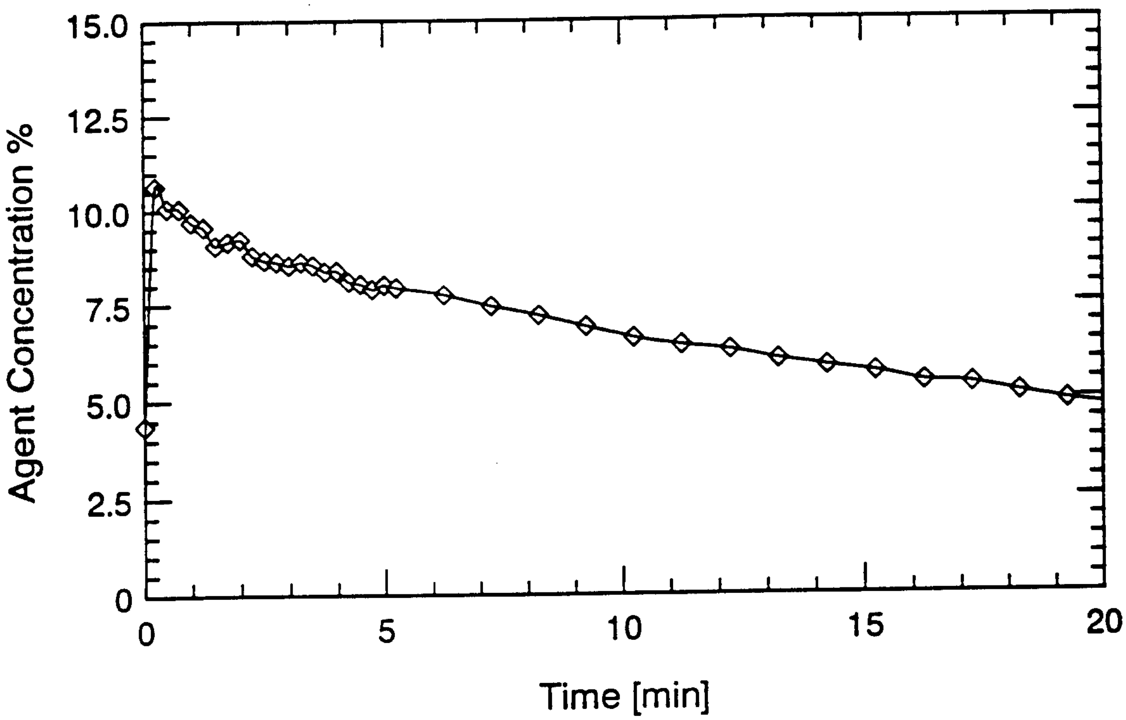



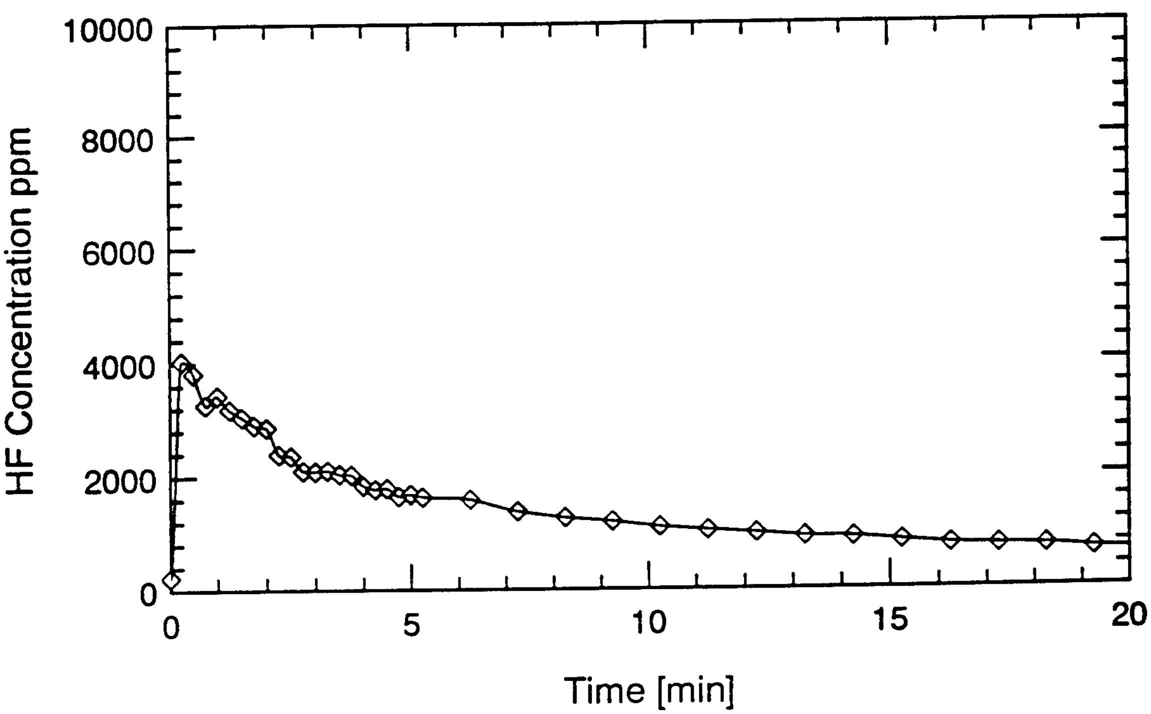

Compartment Temperatures
TEST #37



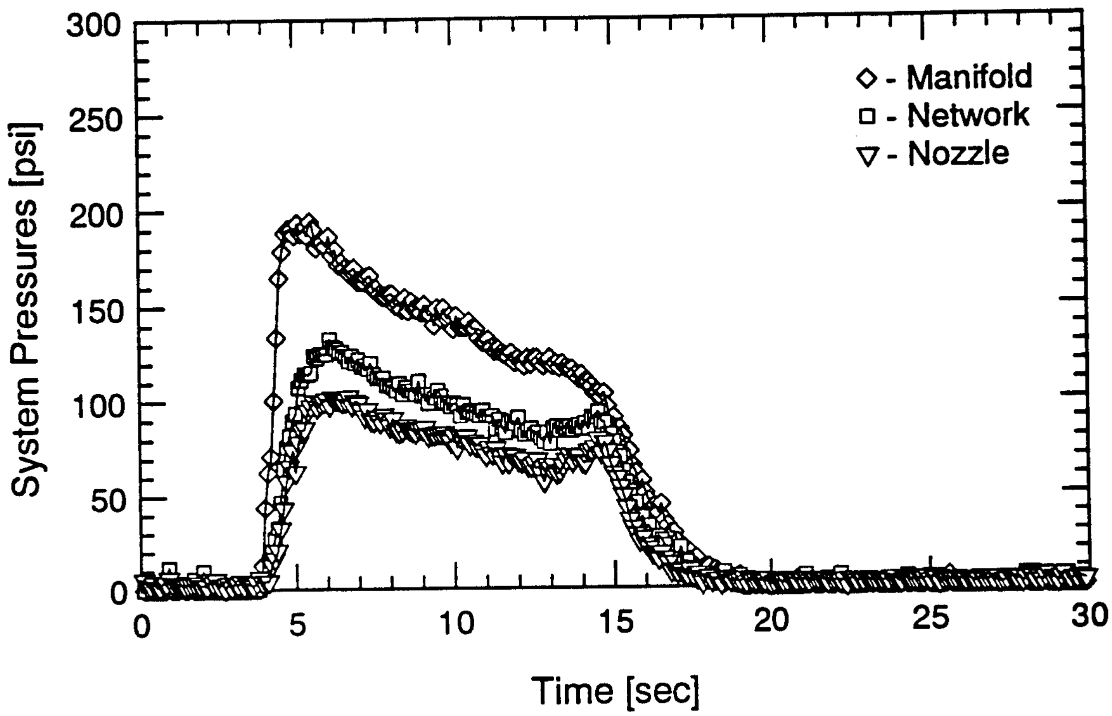



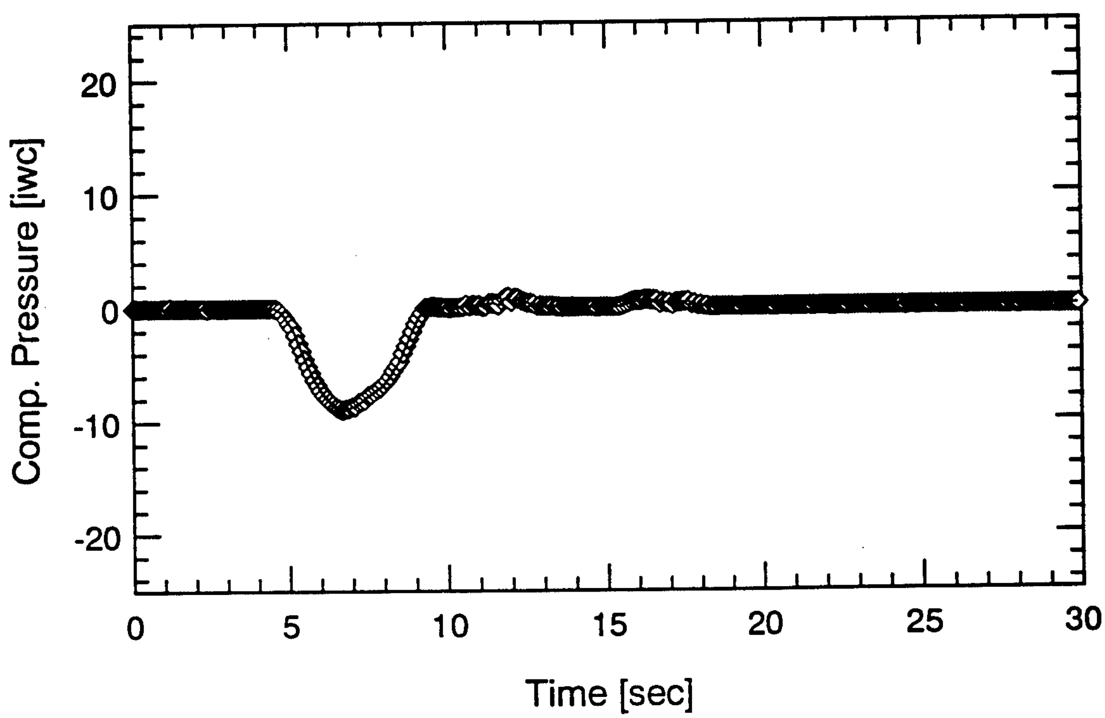

Oxygen Concentrations
TEST #37



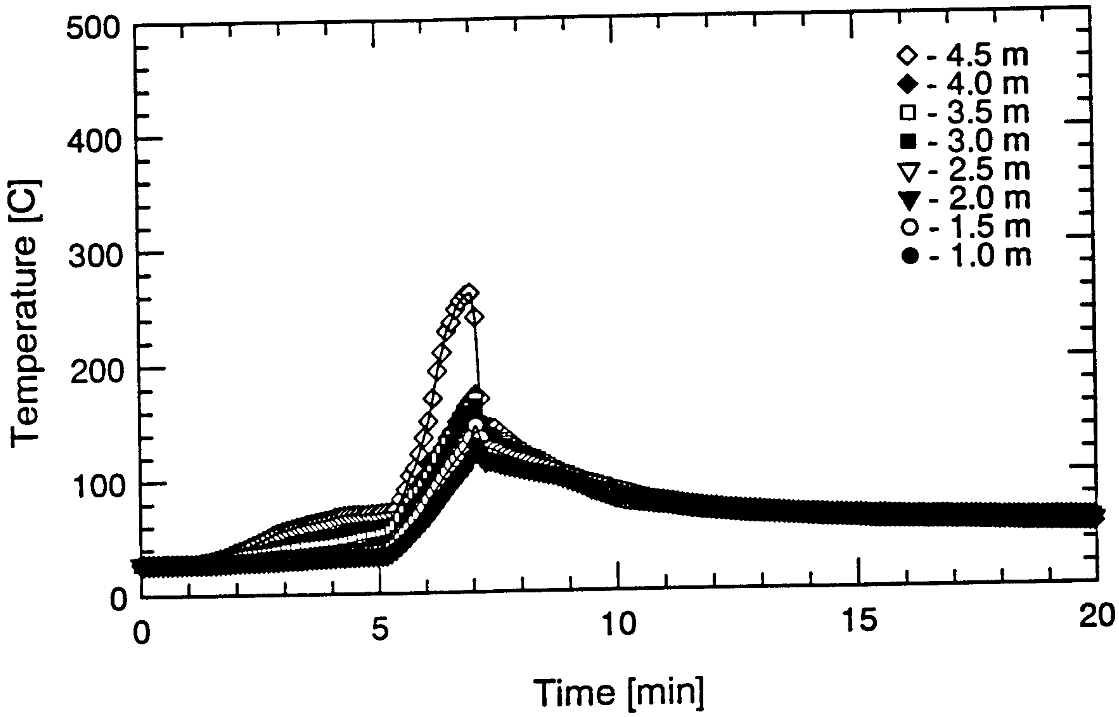



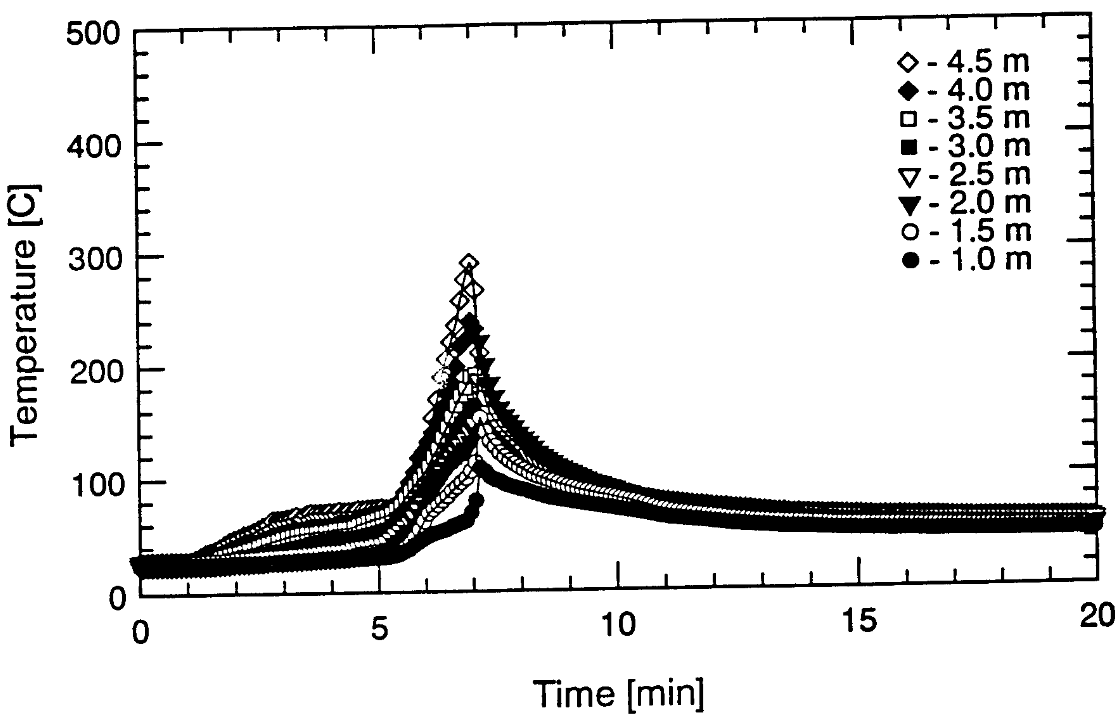

Agent and HF Concentrations
TEST #37



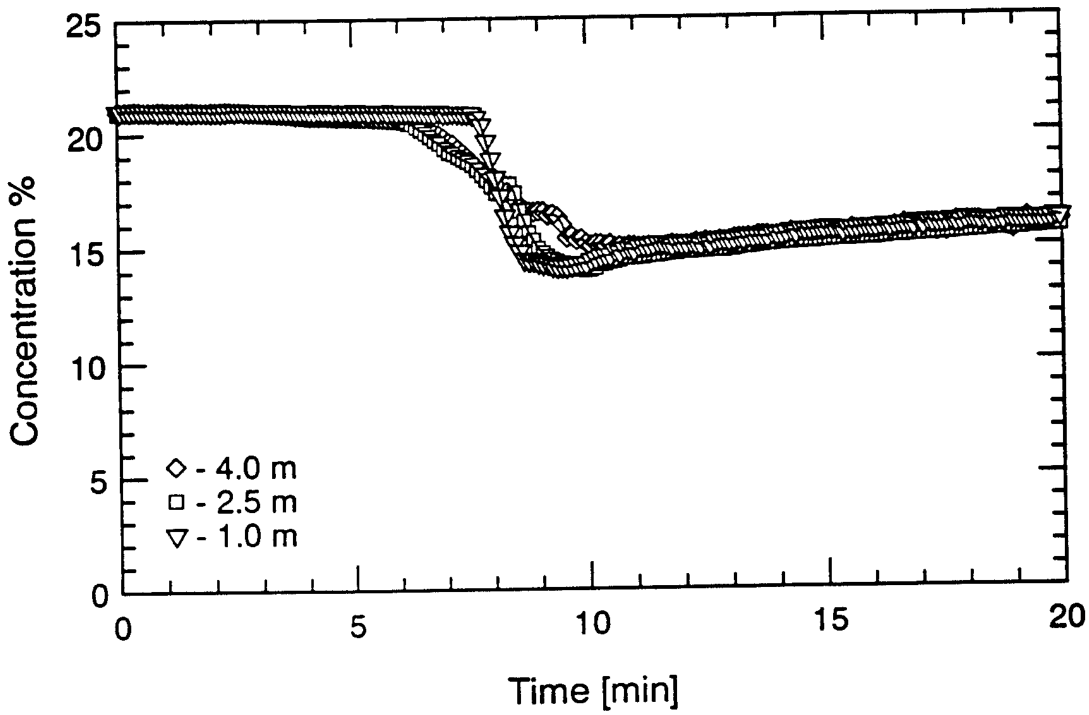



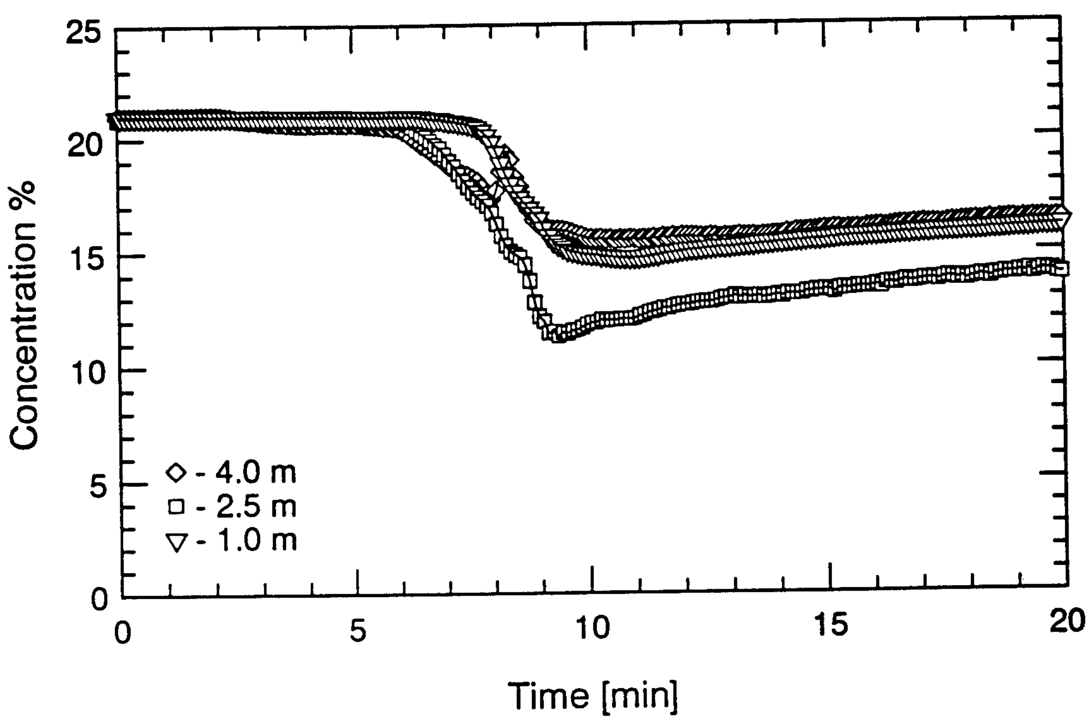

Pressure Measurements
TEST #37



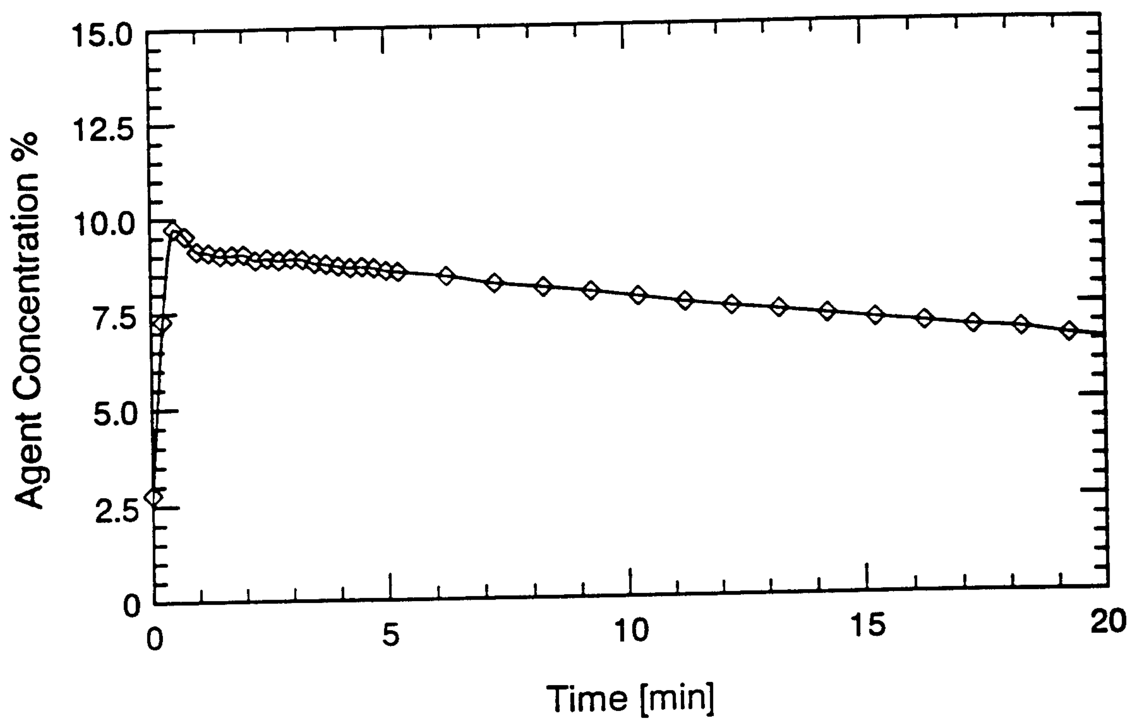



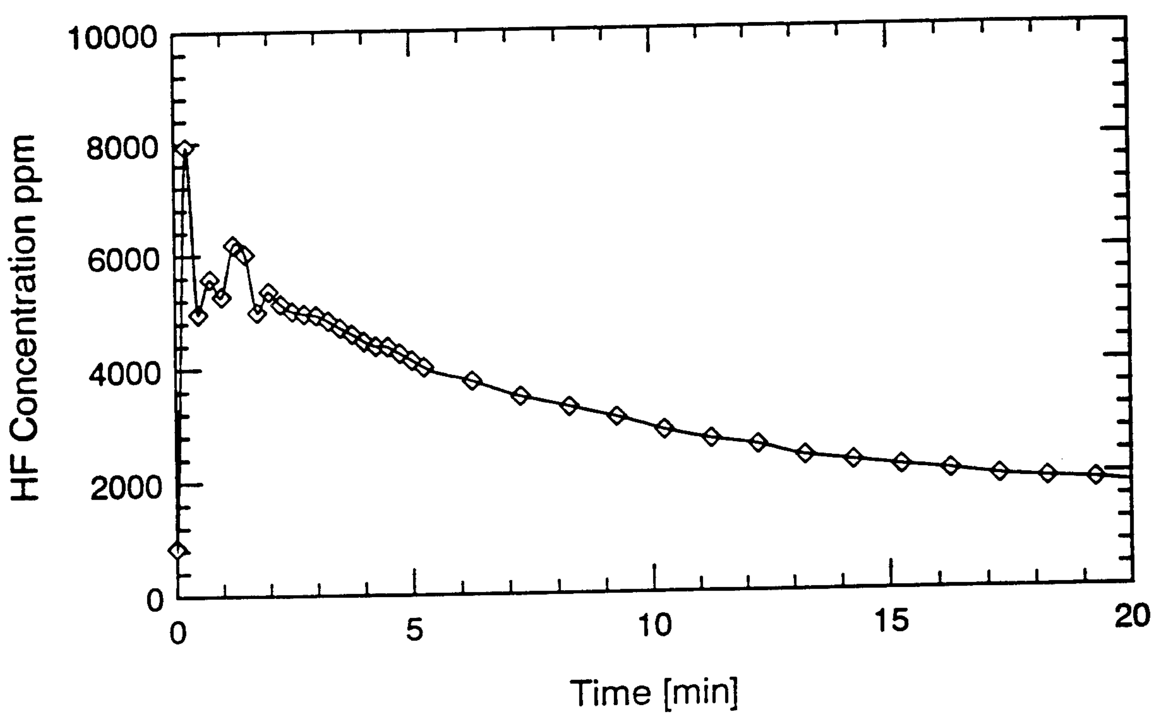

Compartment Temperatures
TEST #38



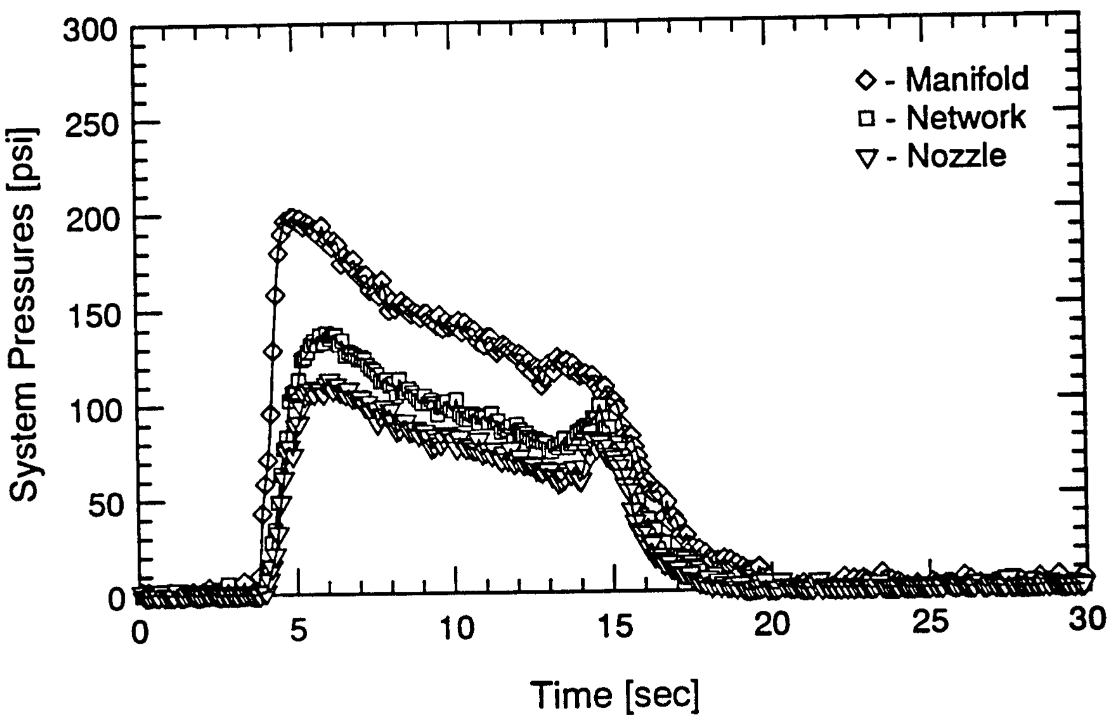



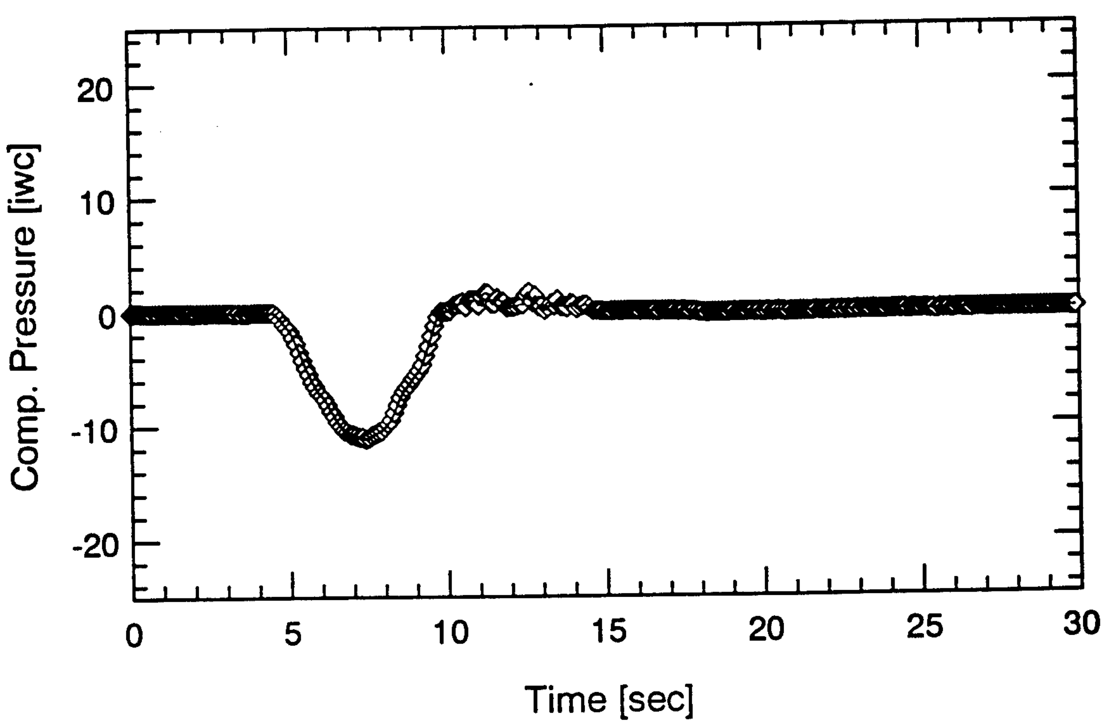

Oxygen Concentrations
TEST #38



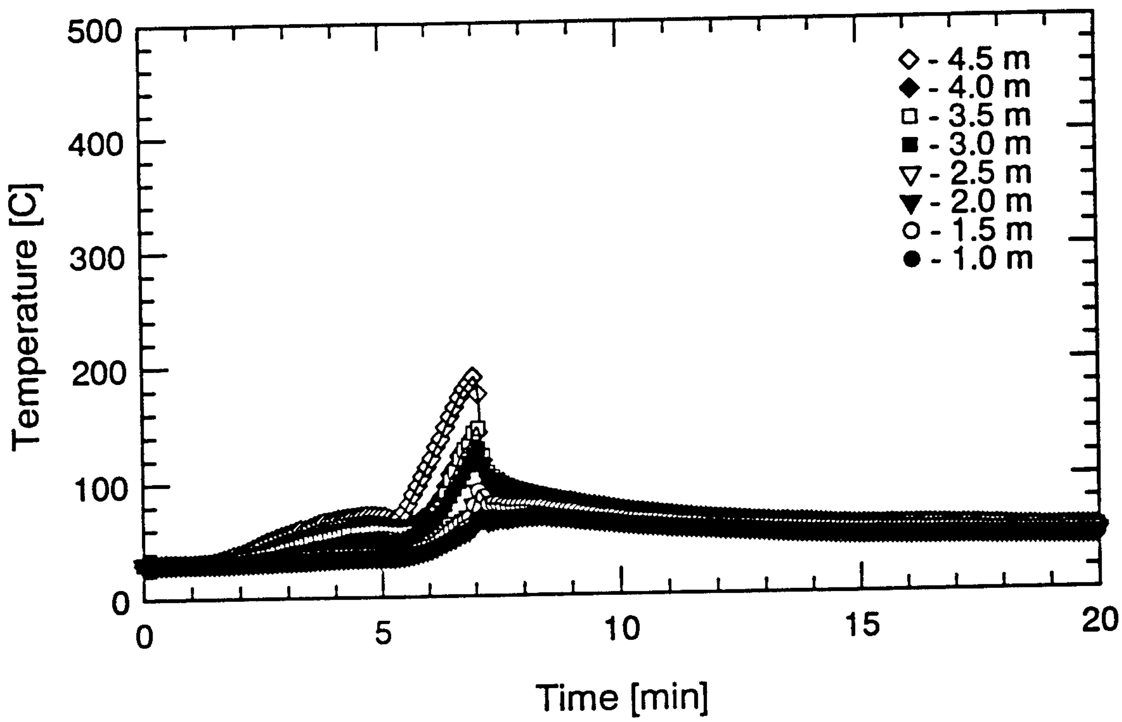



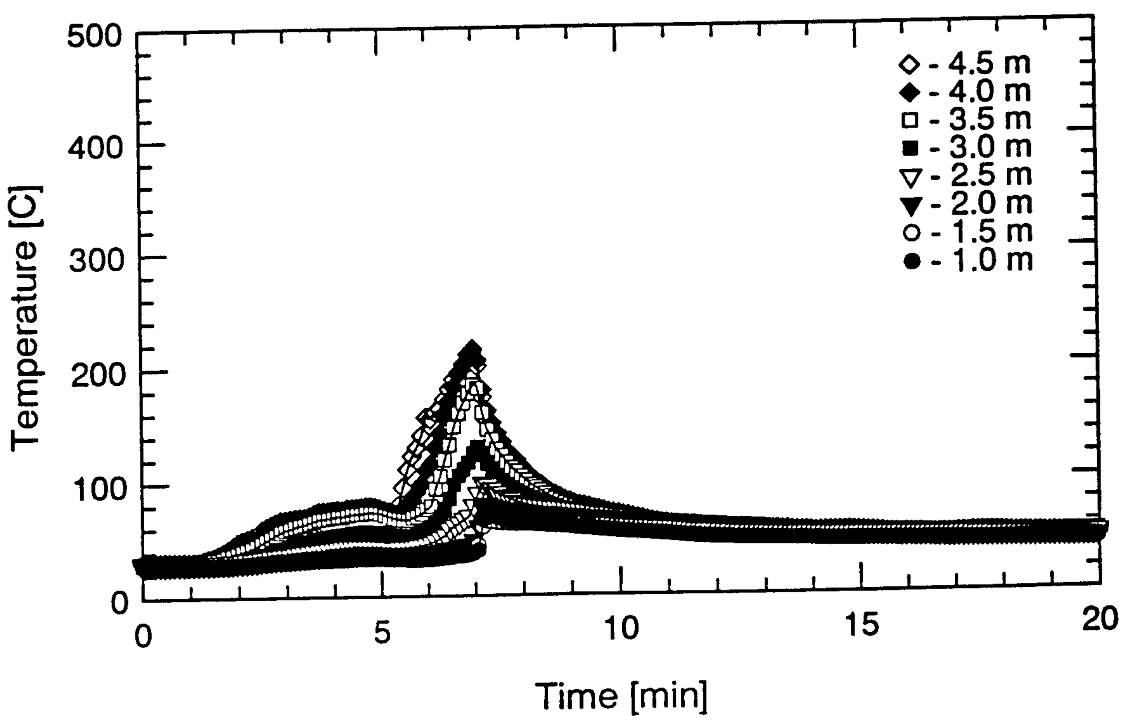

Agent and HF Concentrations
TEST #38



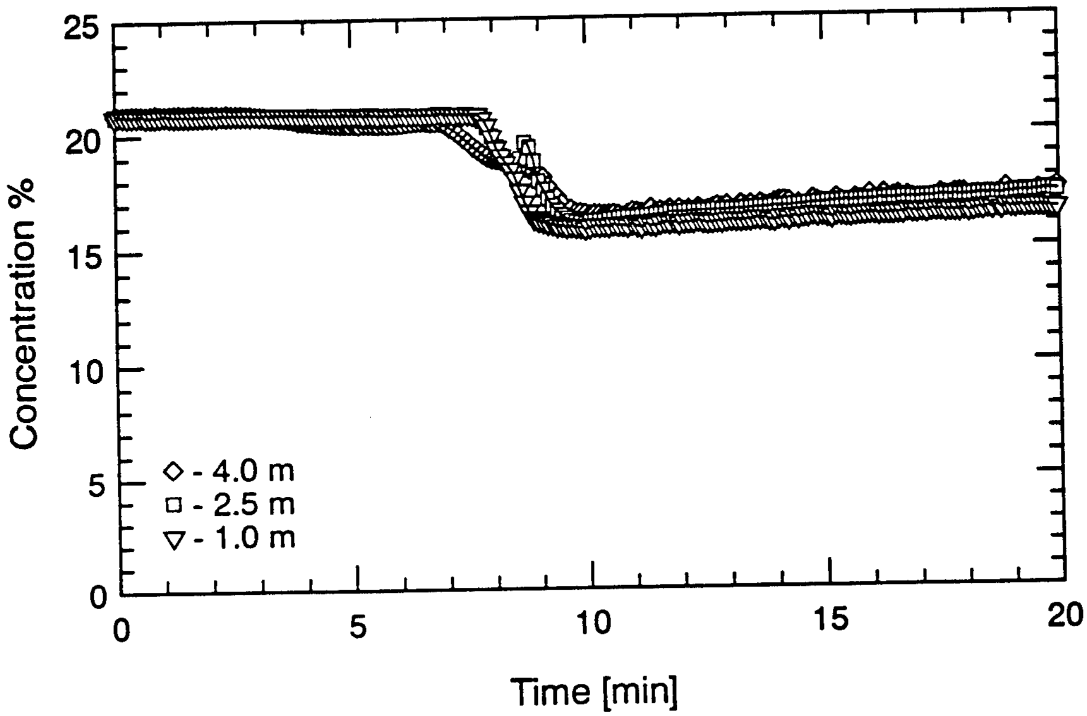



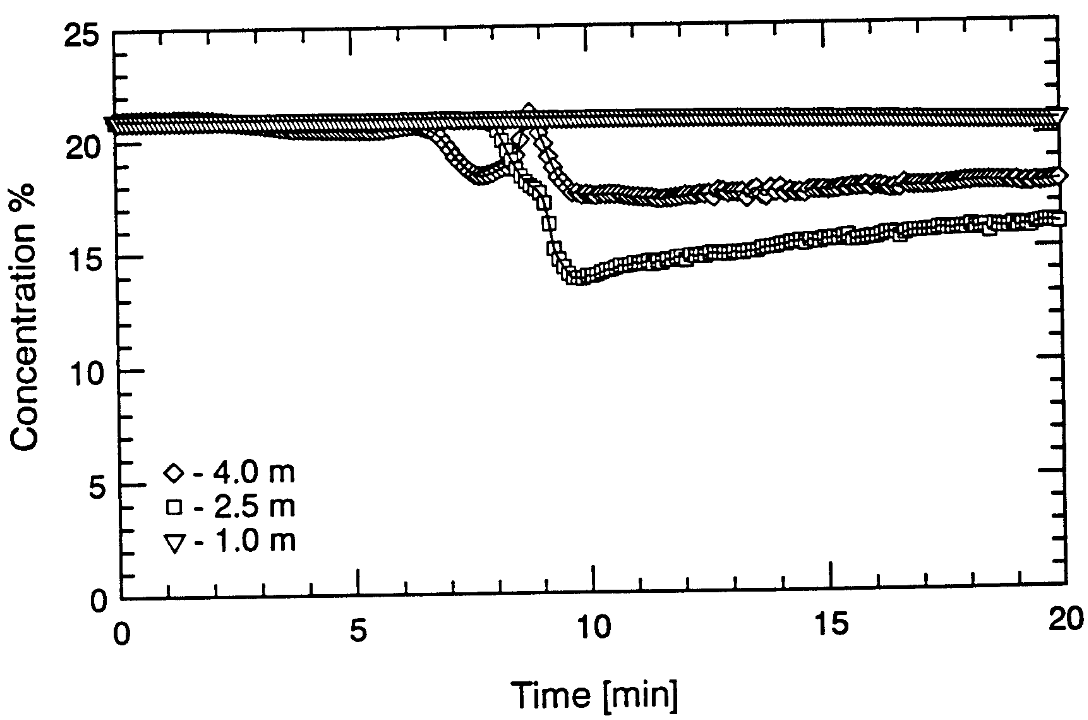

Pressure Measurements
TEST #38



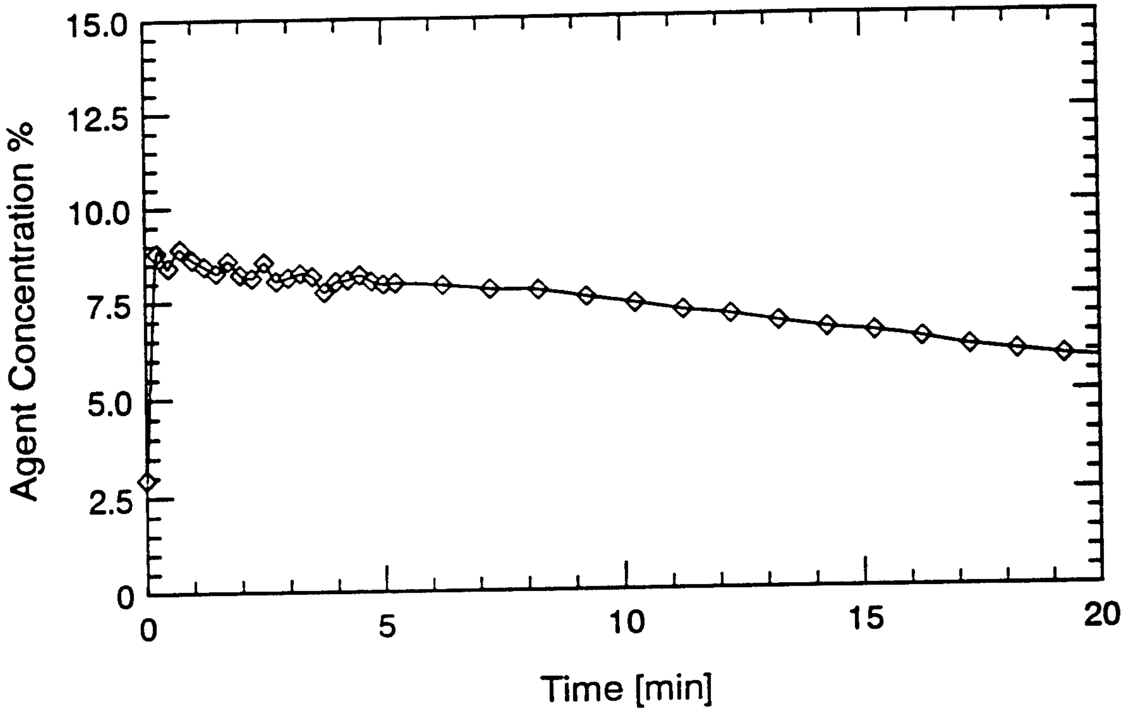



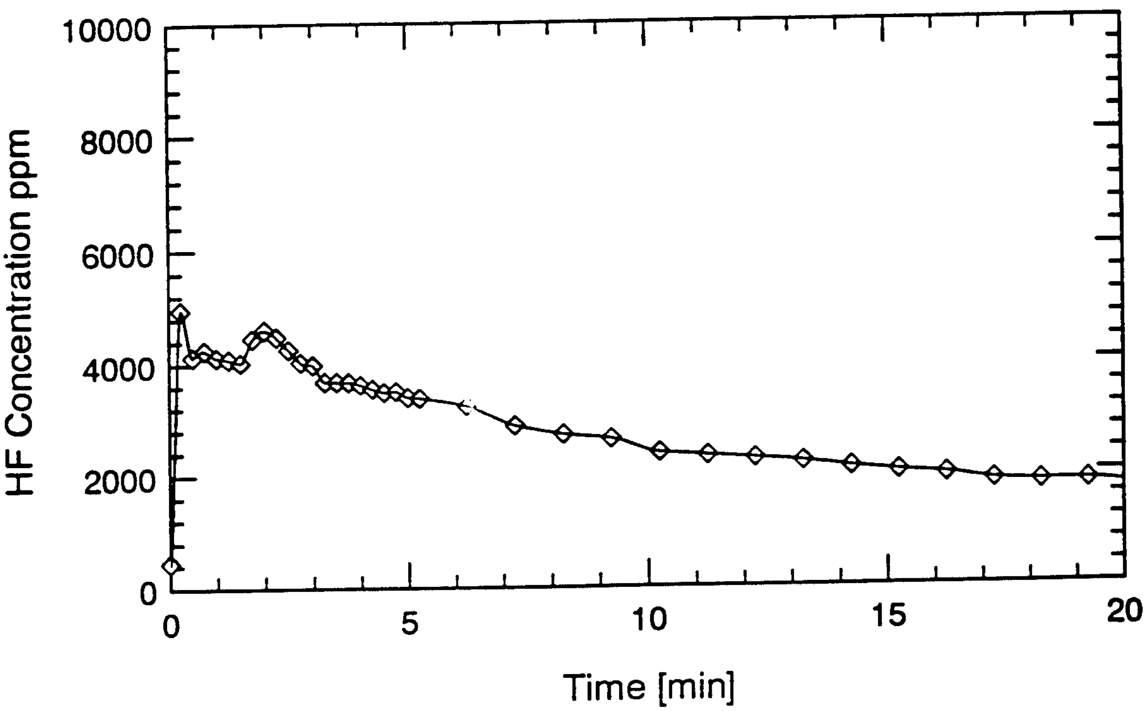

Compartment Temperatures
TEST #39



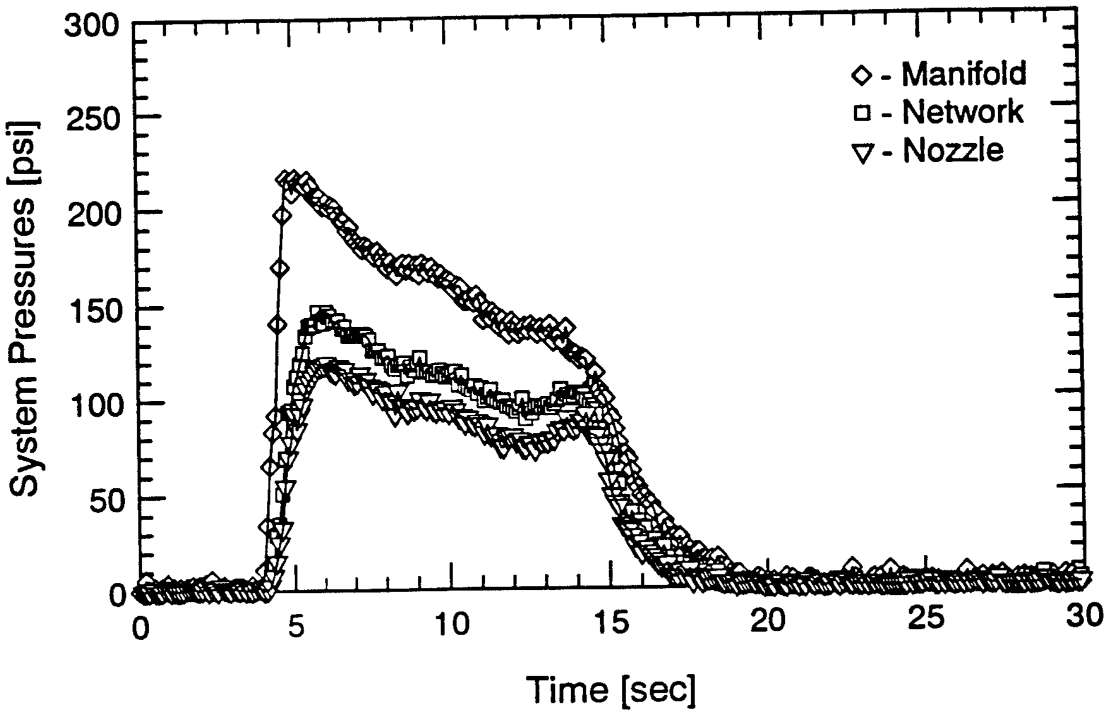



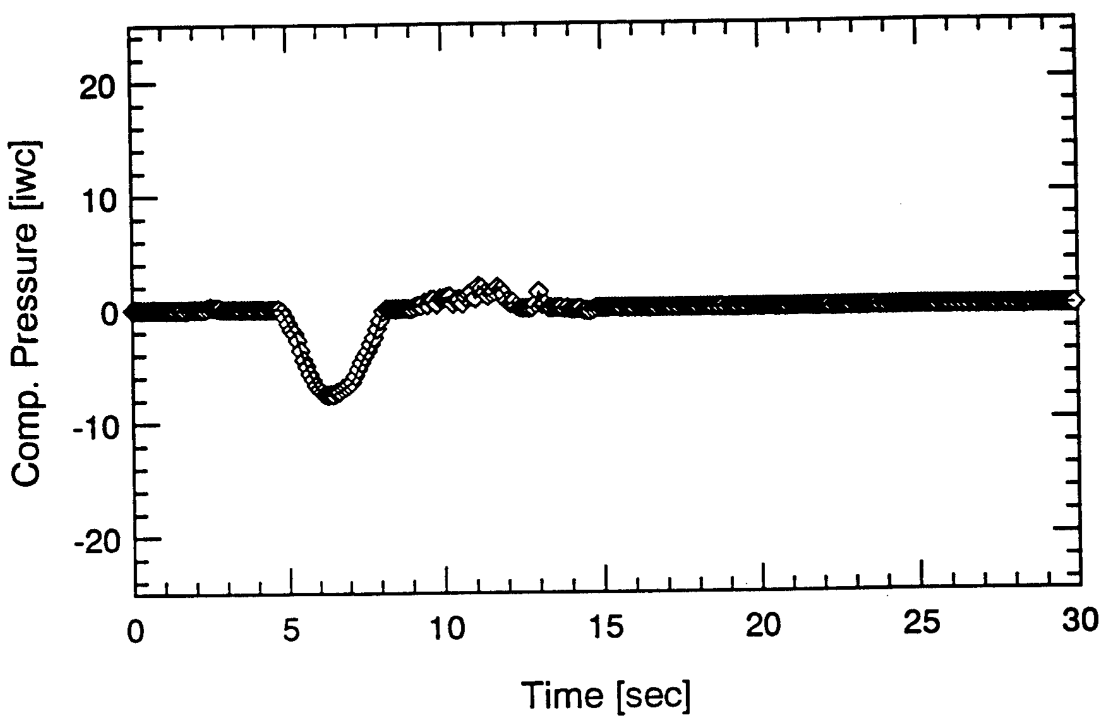

Oxygen Concentrations
TEST #39



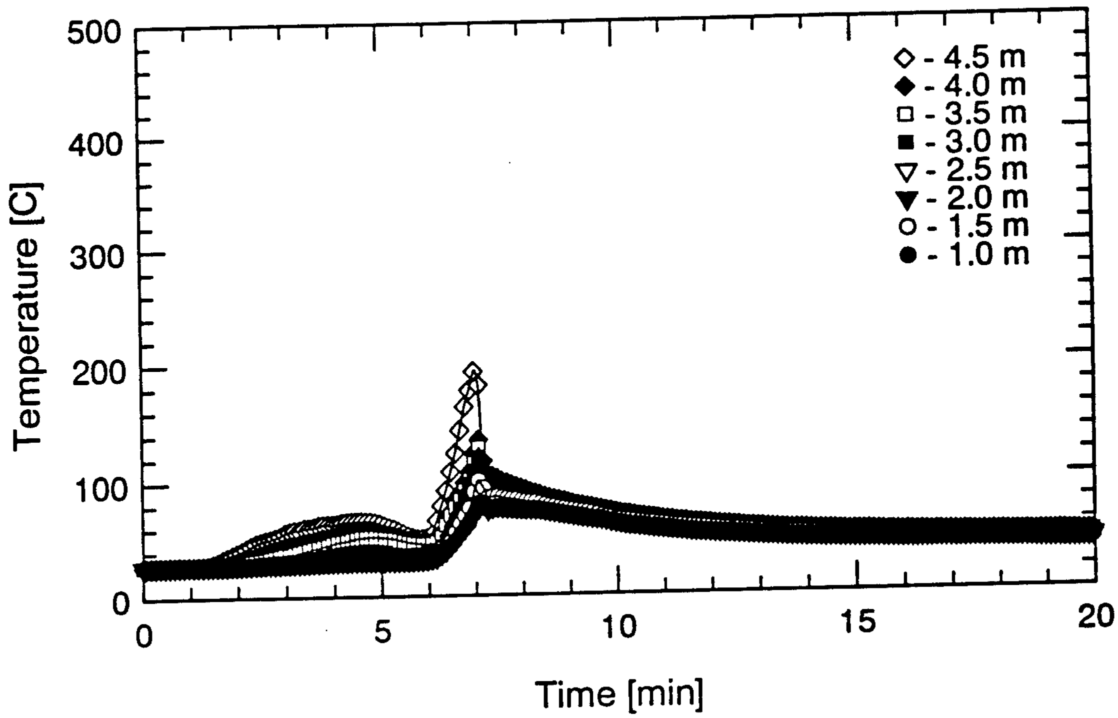



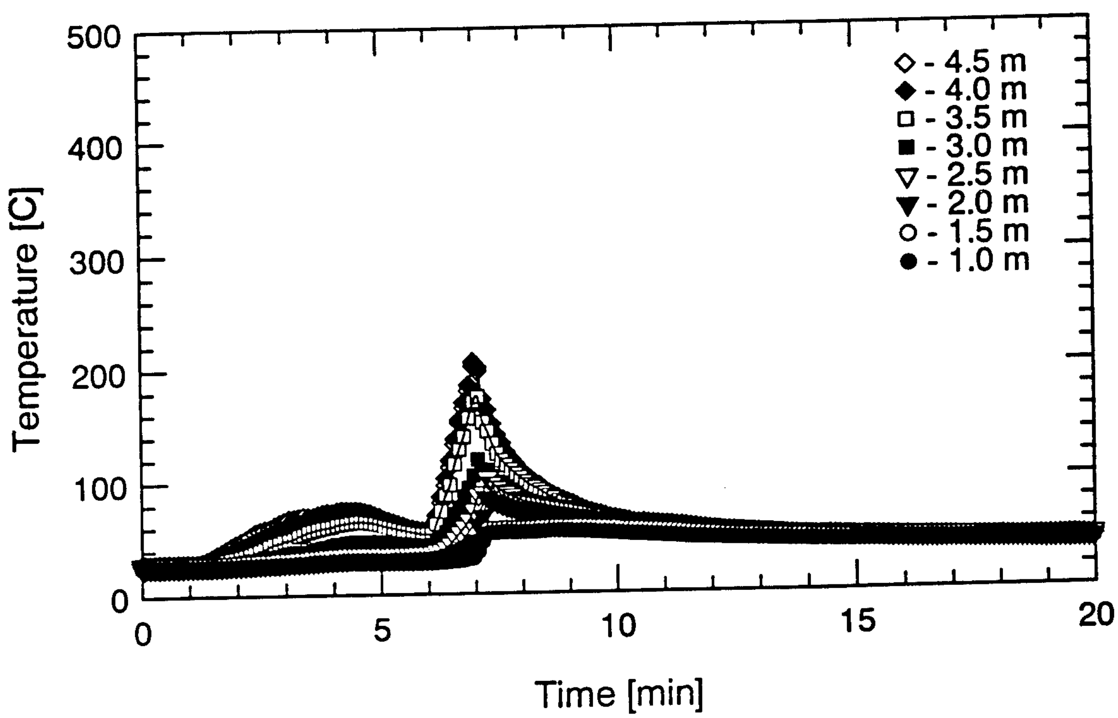

Agent and HF Concentrations
TEST #39



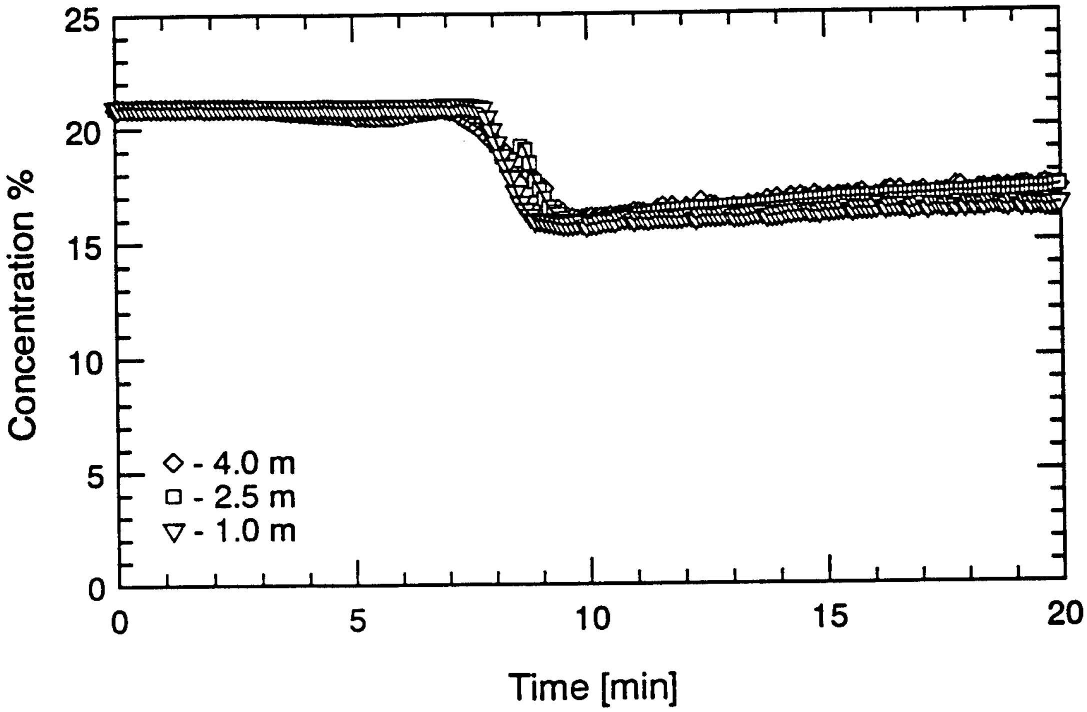



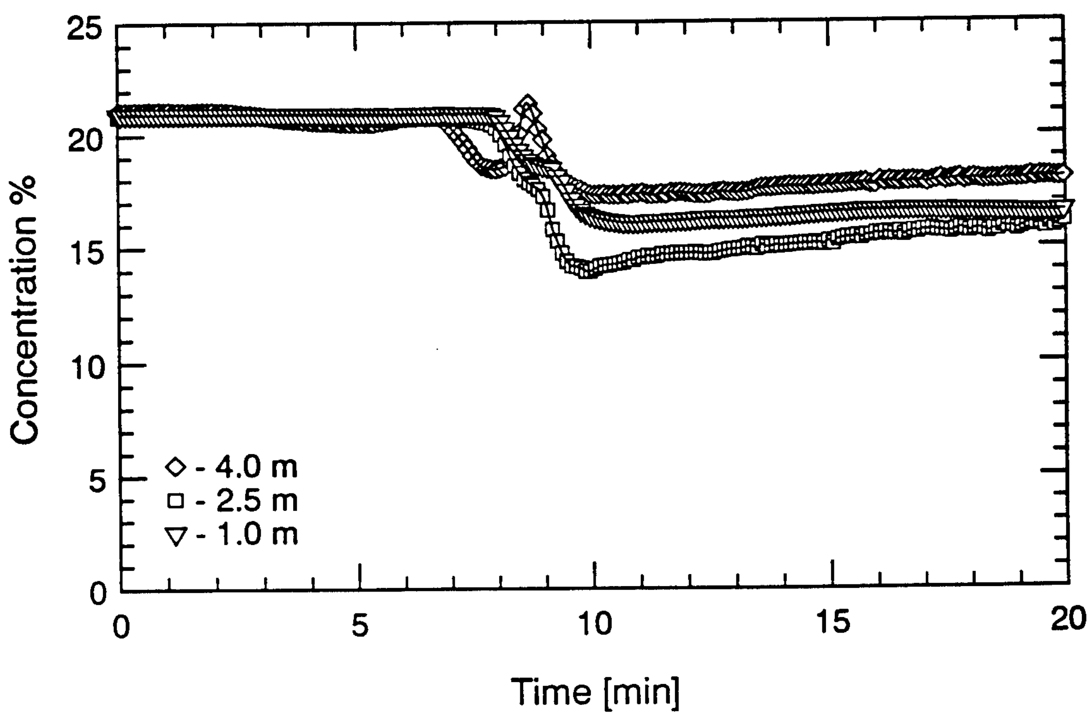

Pressure Measurements
TEST #39



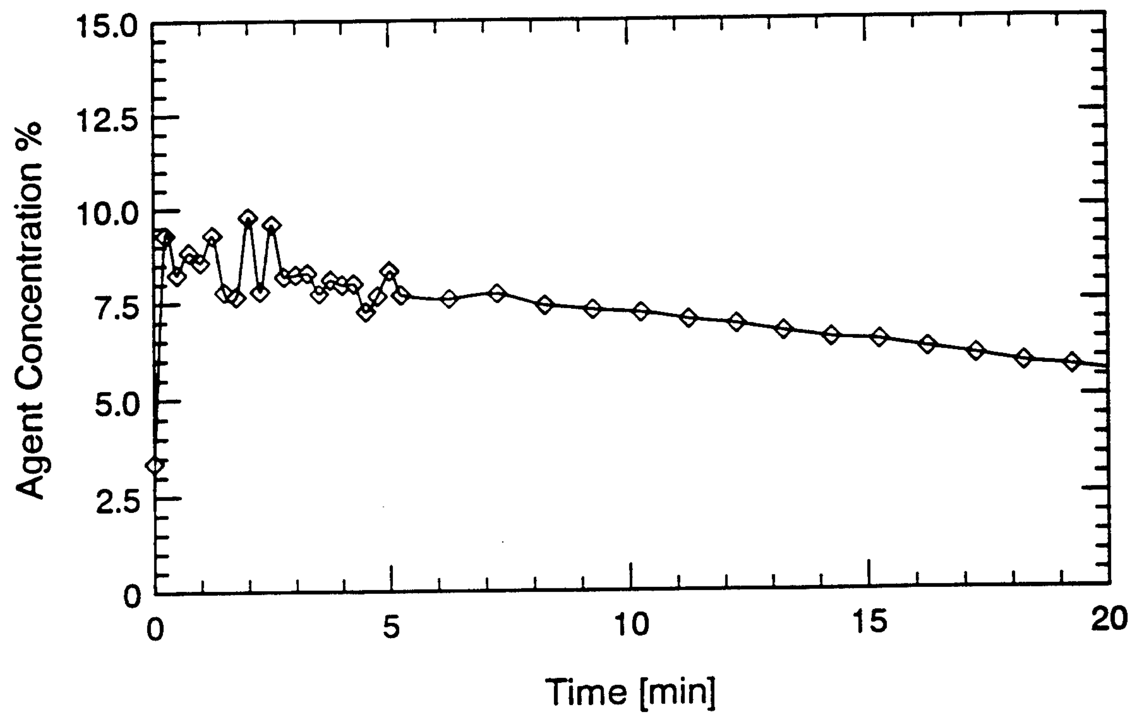



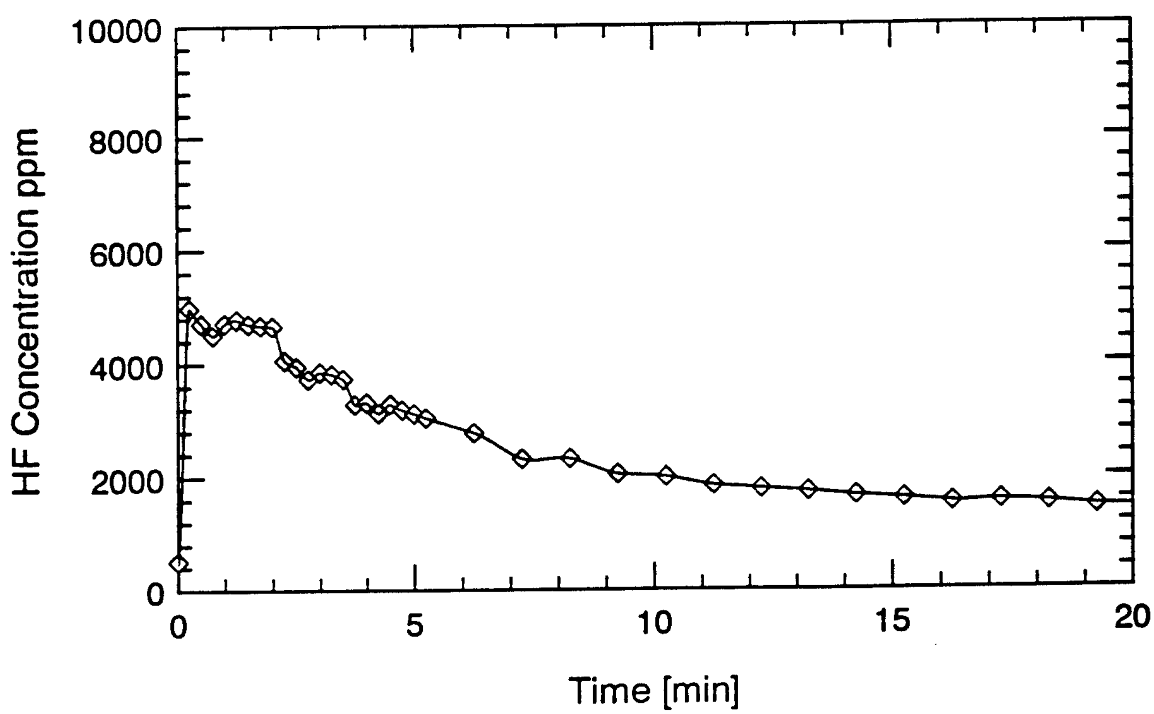

Compartment Temperatures
TEST #40




Oxygen Concentrations
TEST #40




Agent and HF Concentrations
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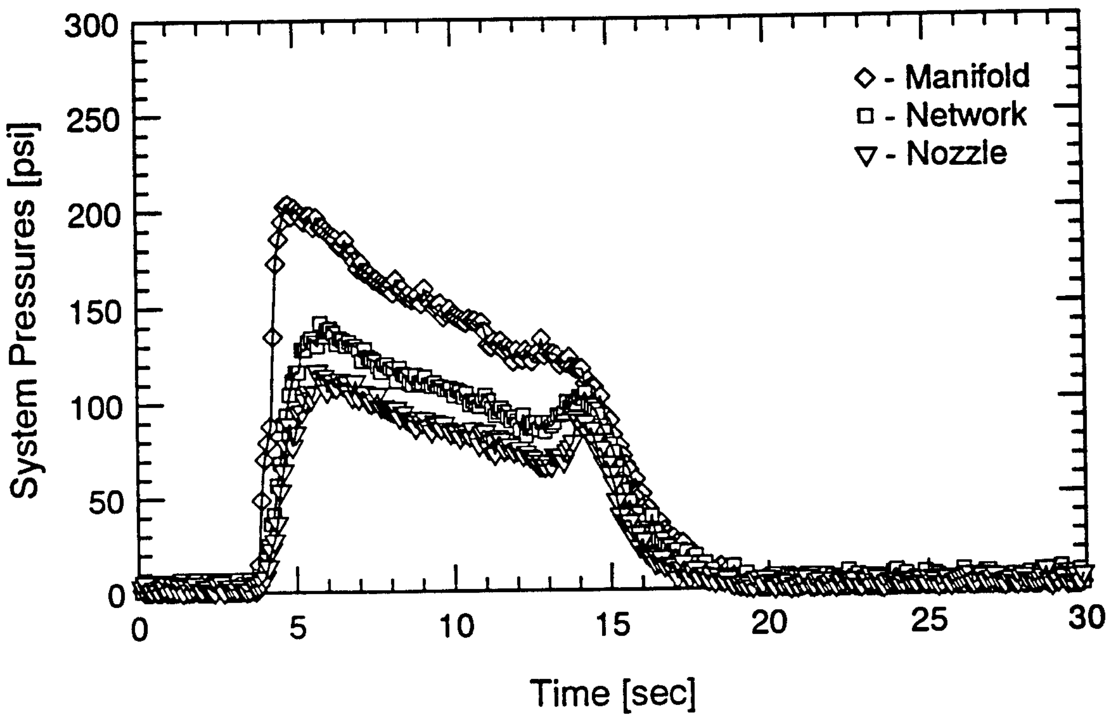
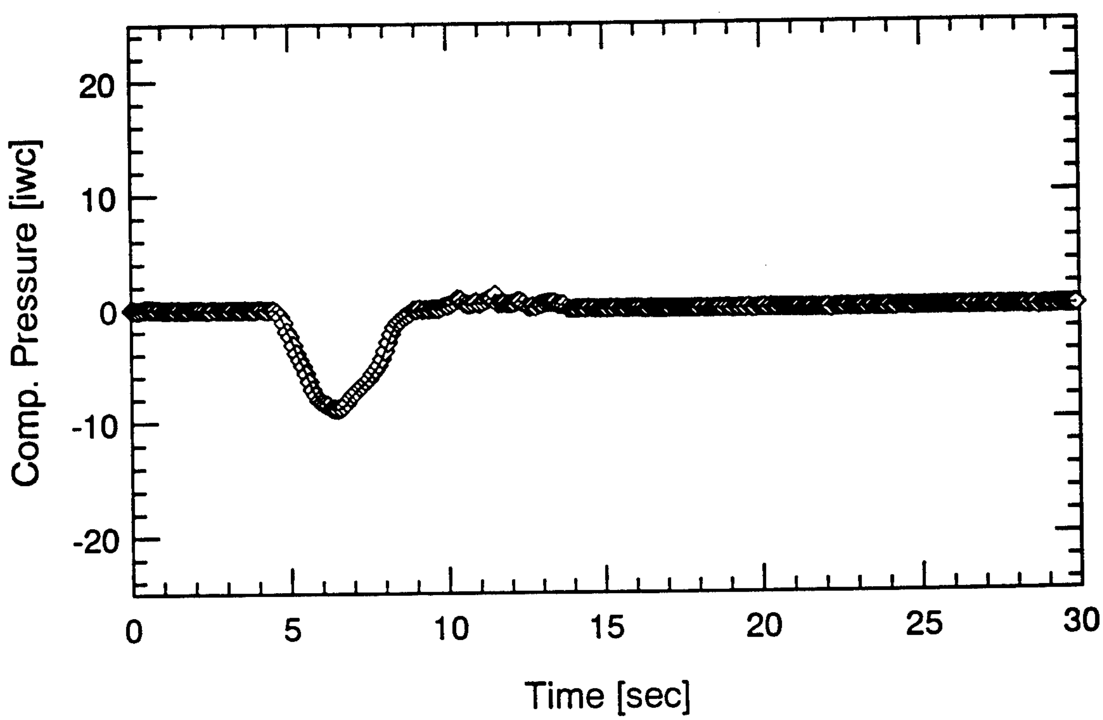
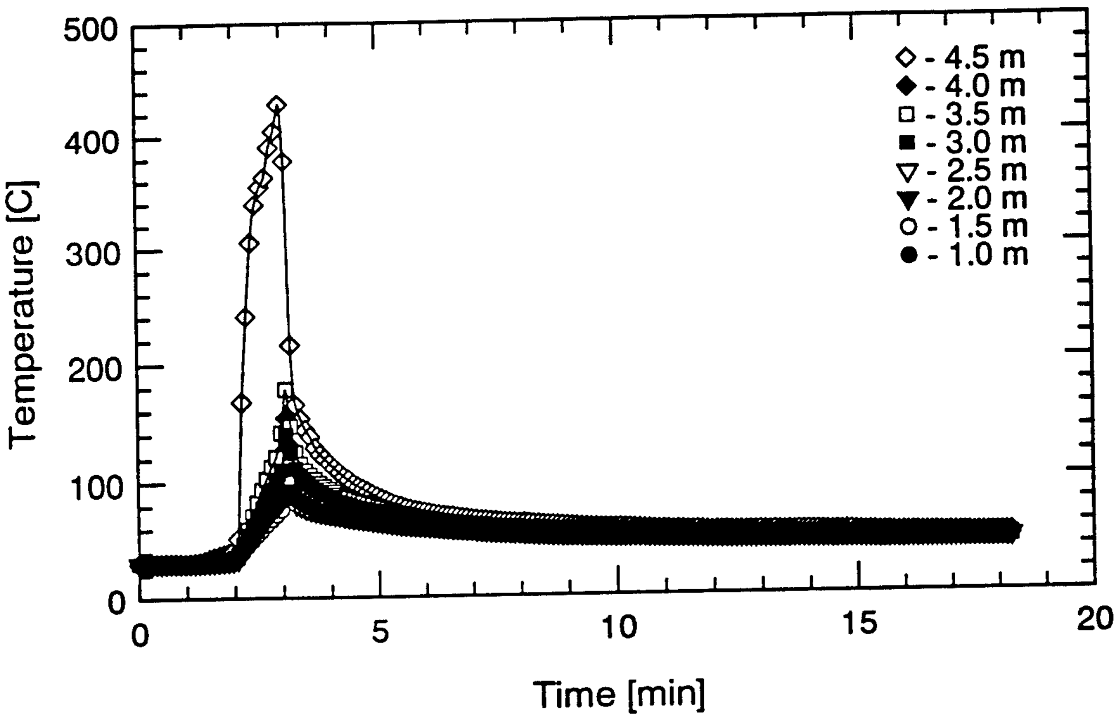
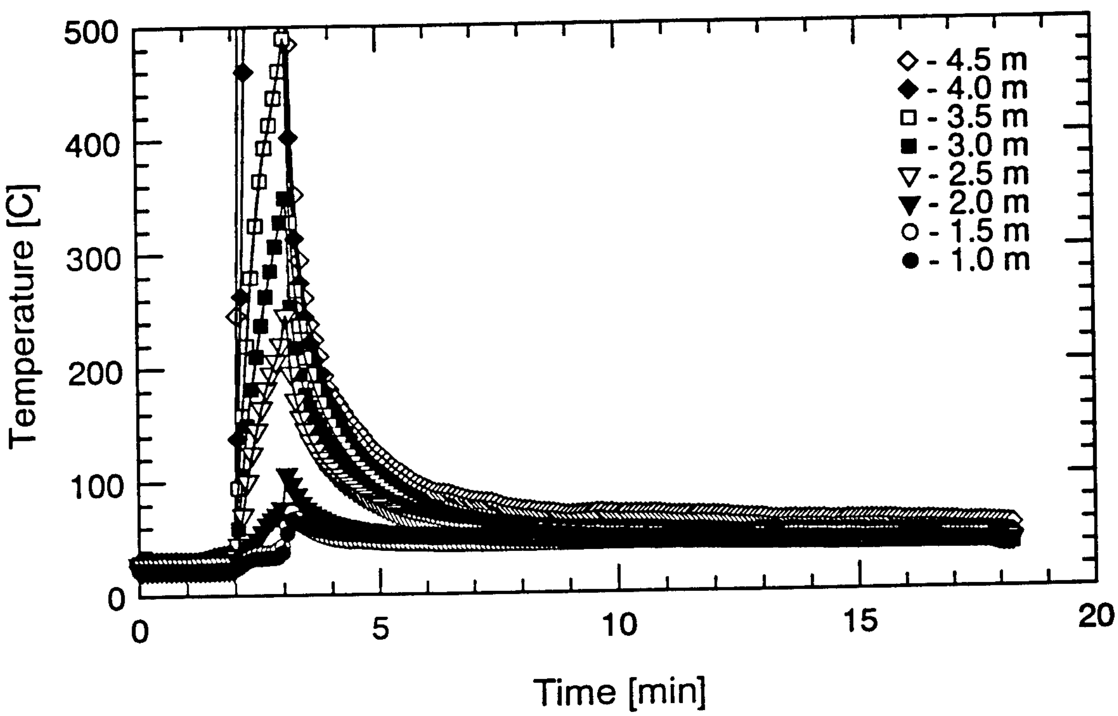



Pressure Measurements
TEST #40




Compartment Temperatures
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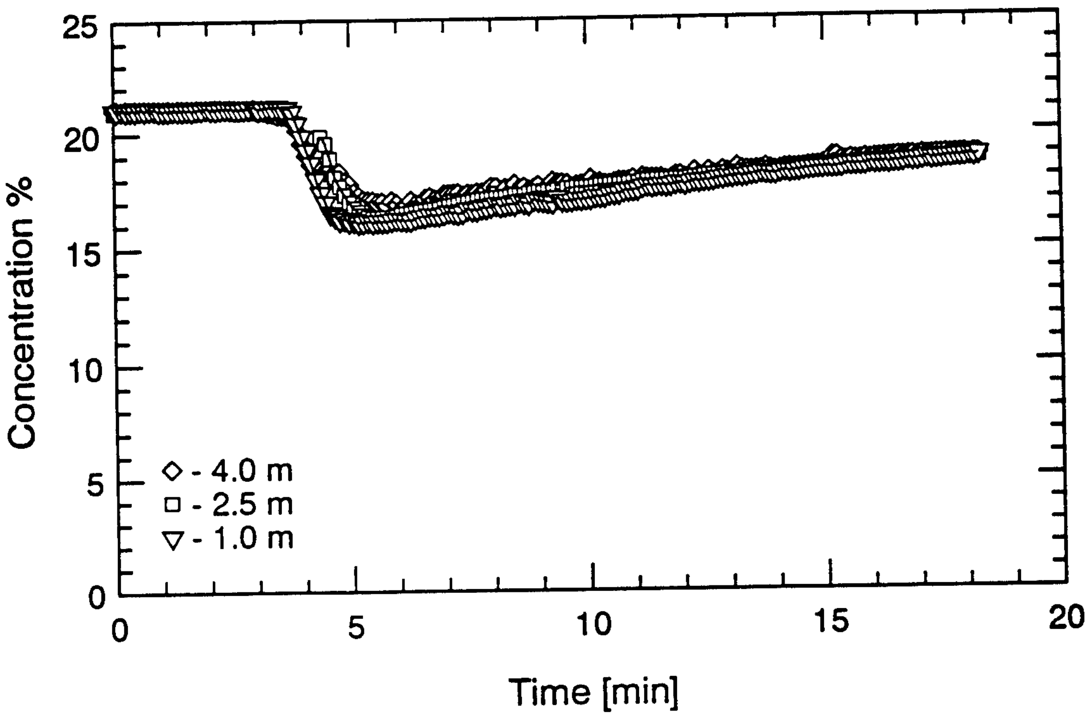


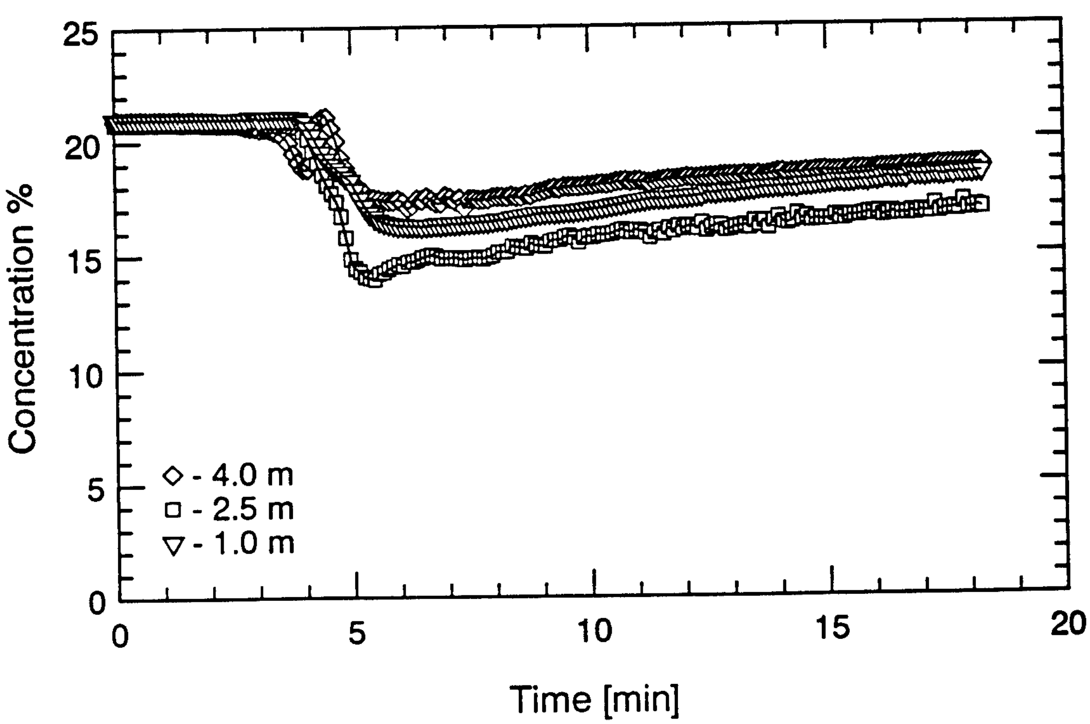


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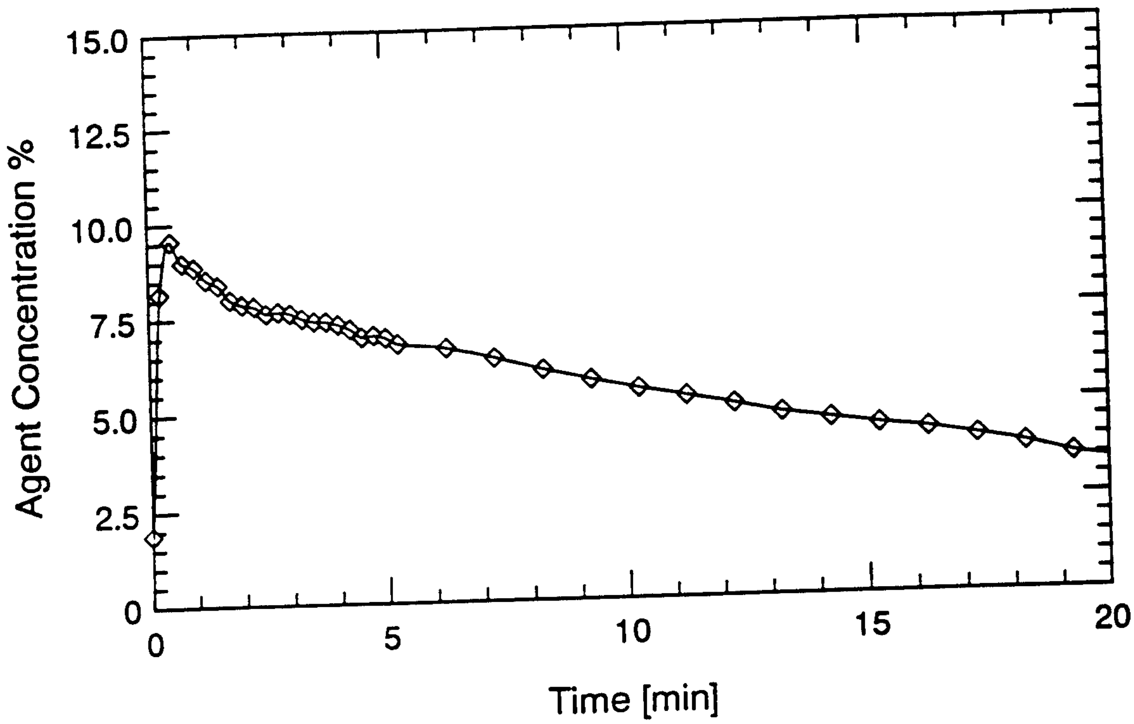


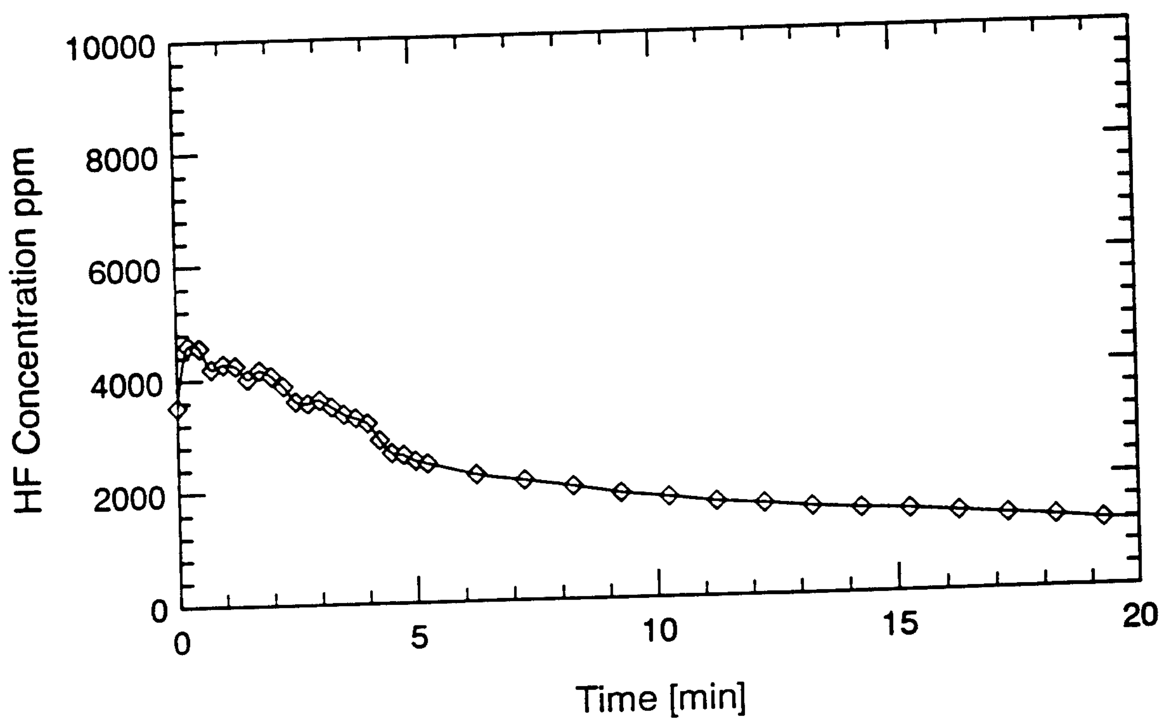


Agent and HF Concentrations
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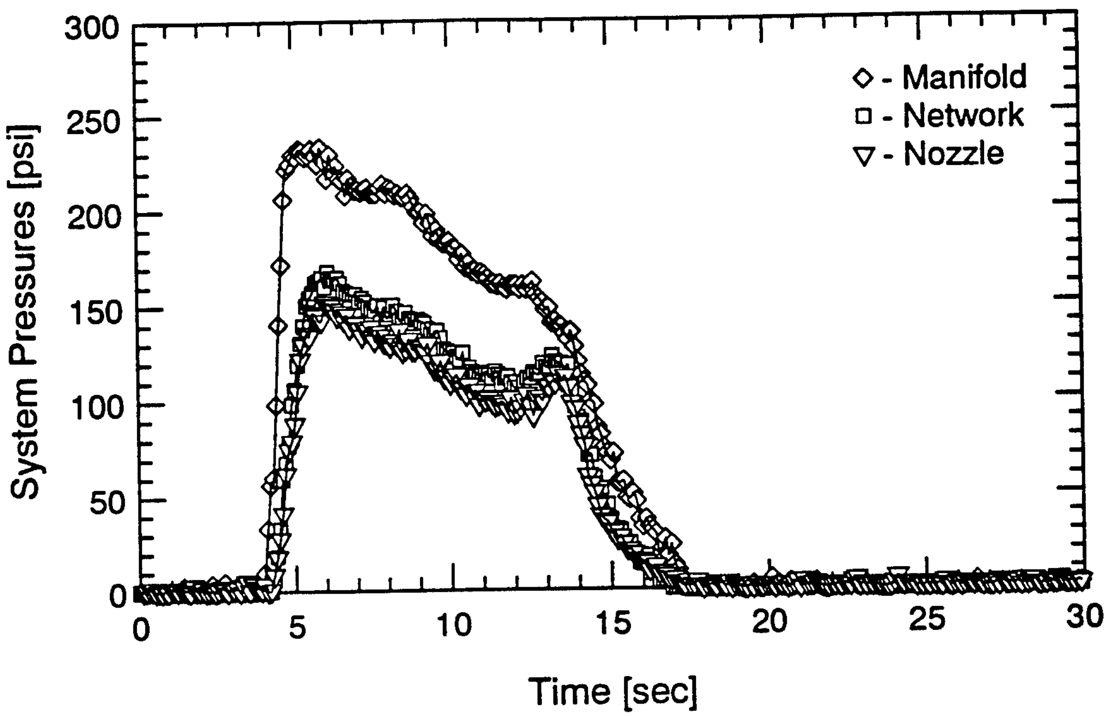
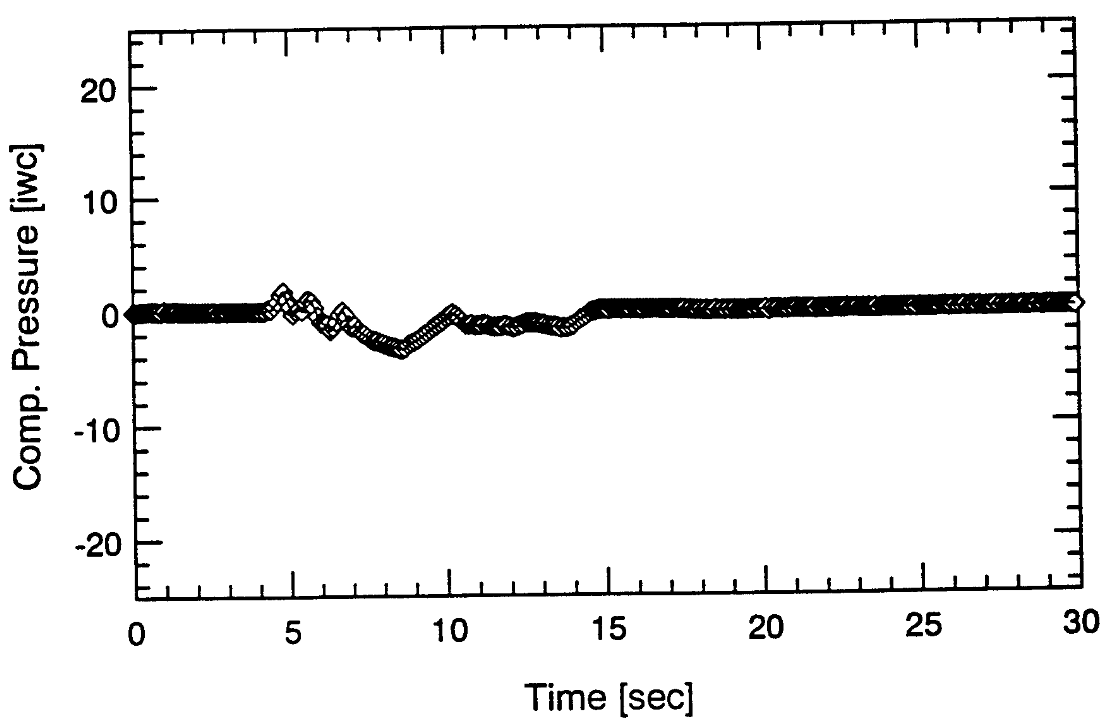
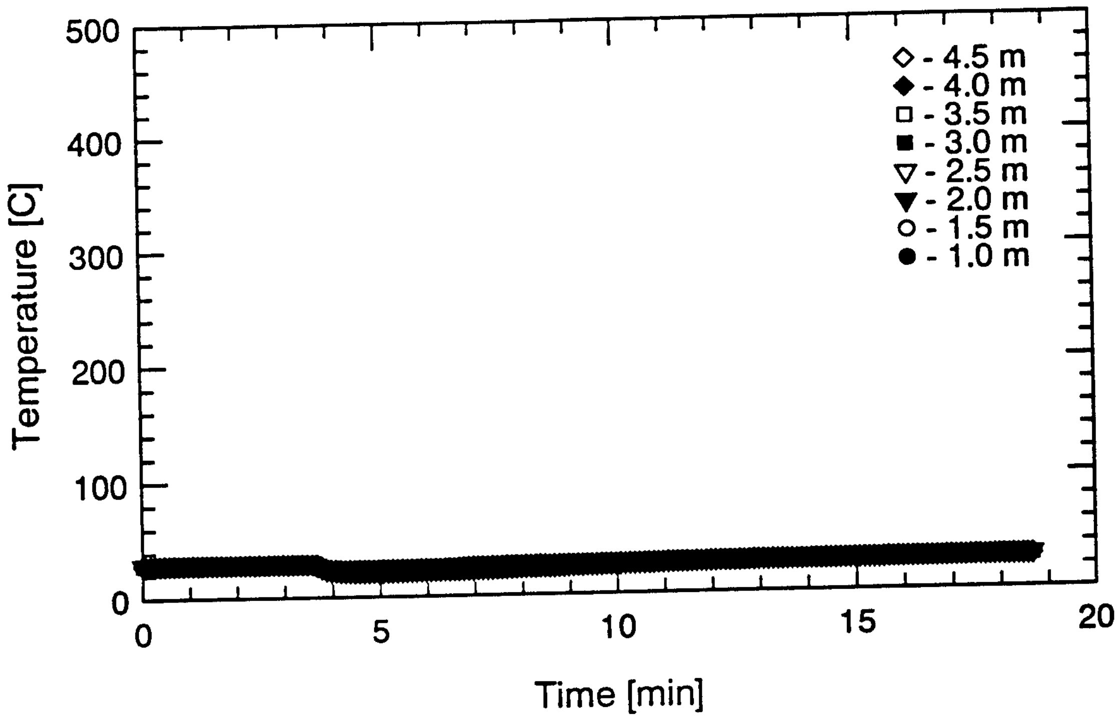
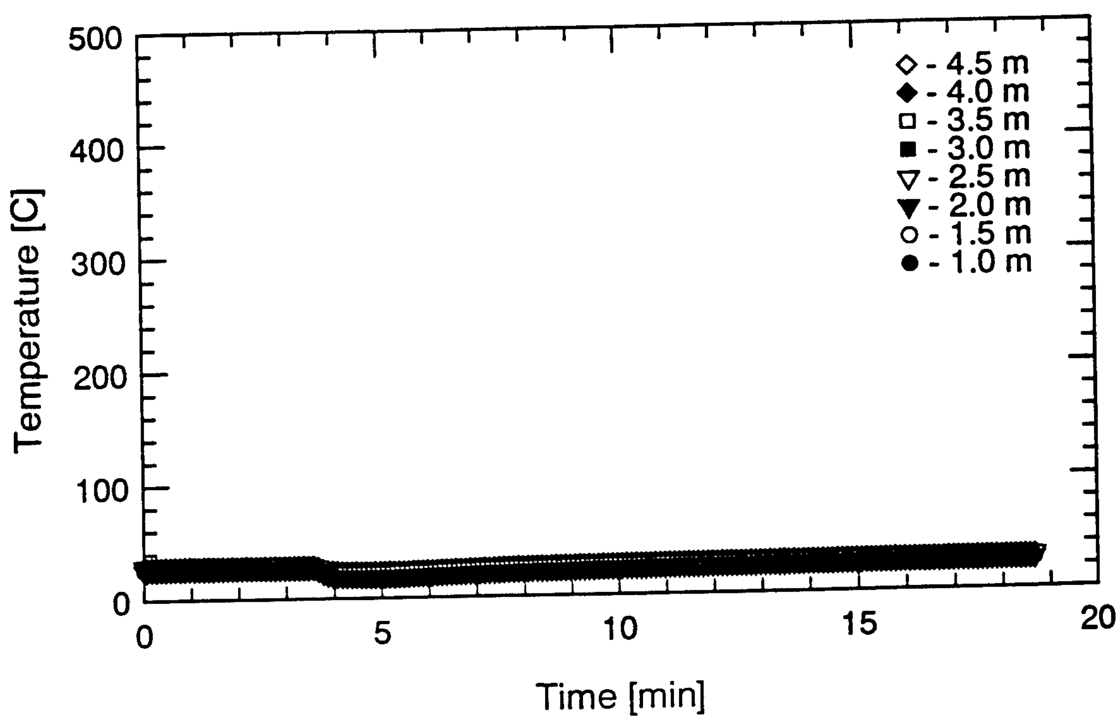


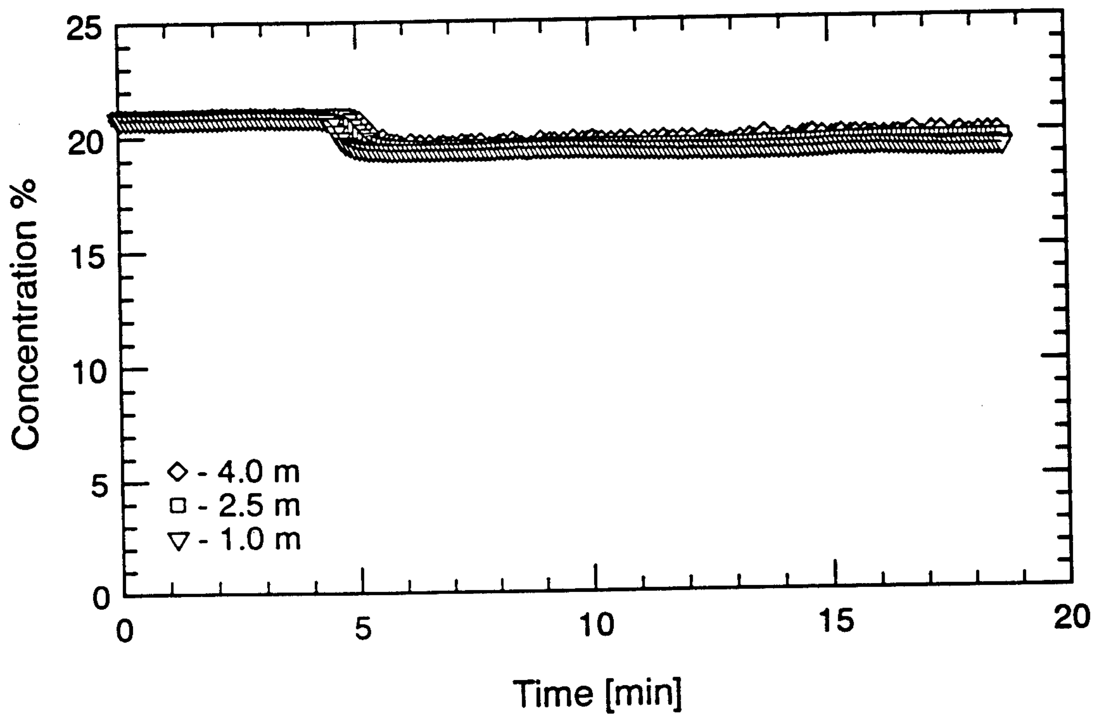



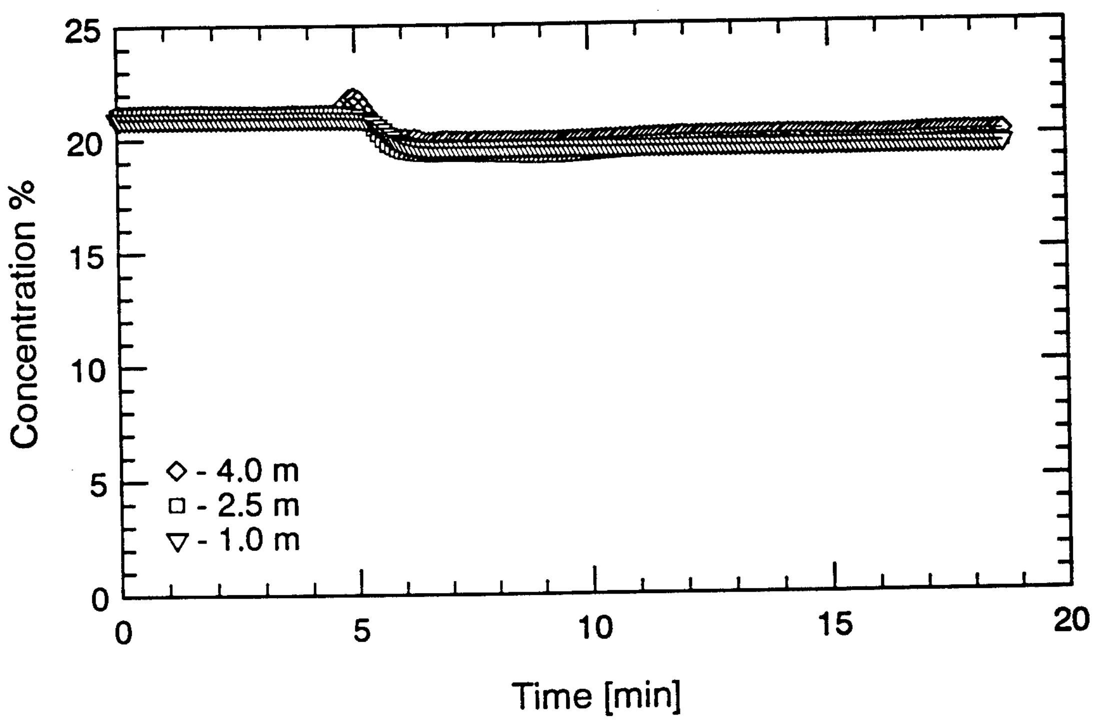

Pressure Measurements
TEST #41




Compartment Temperatures
TEST #42

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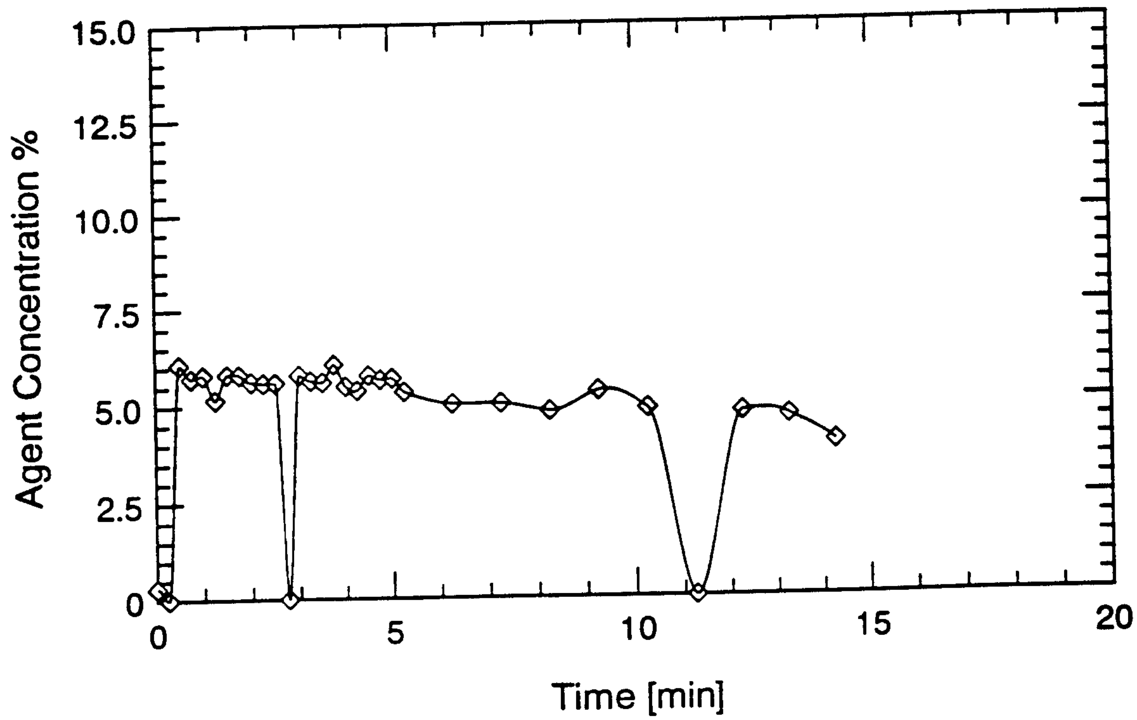
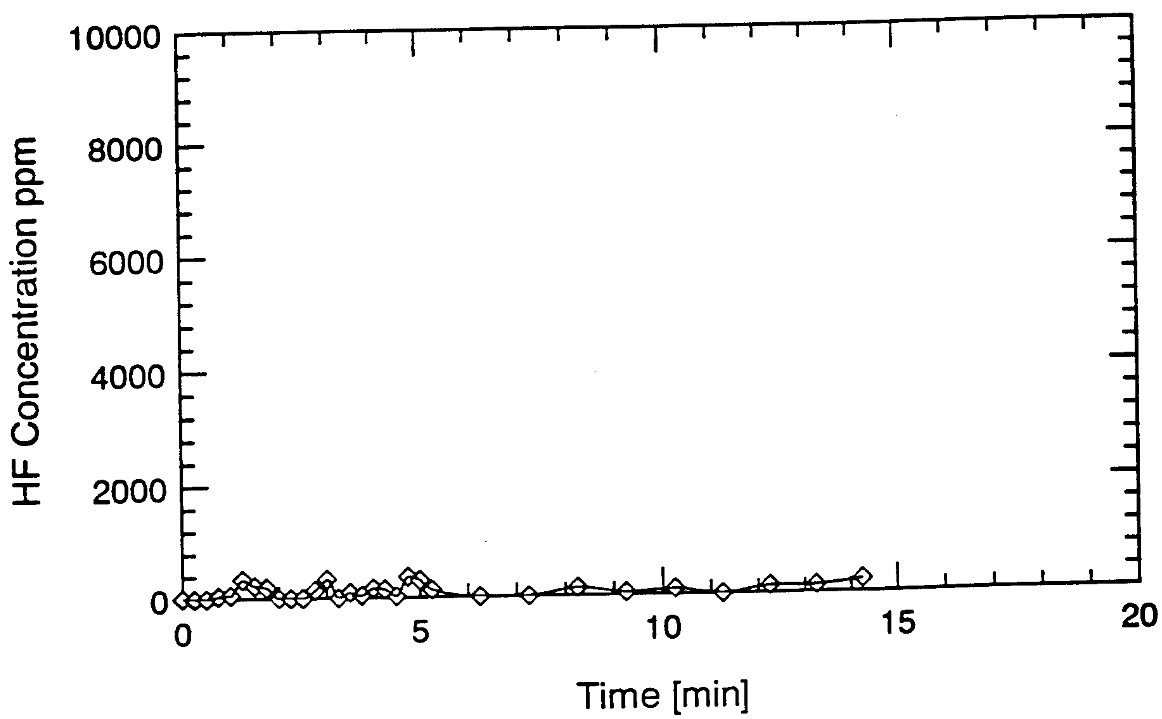
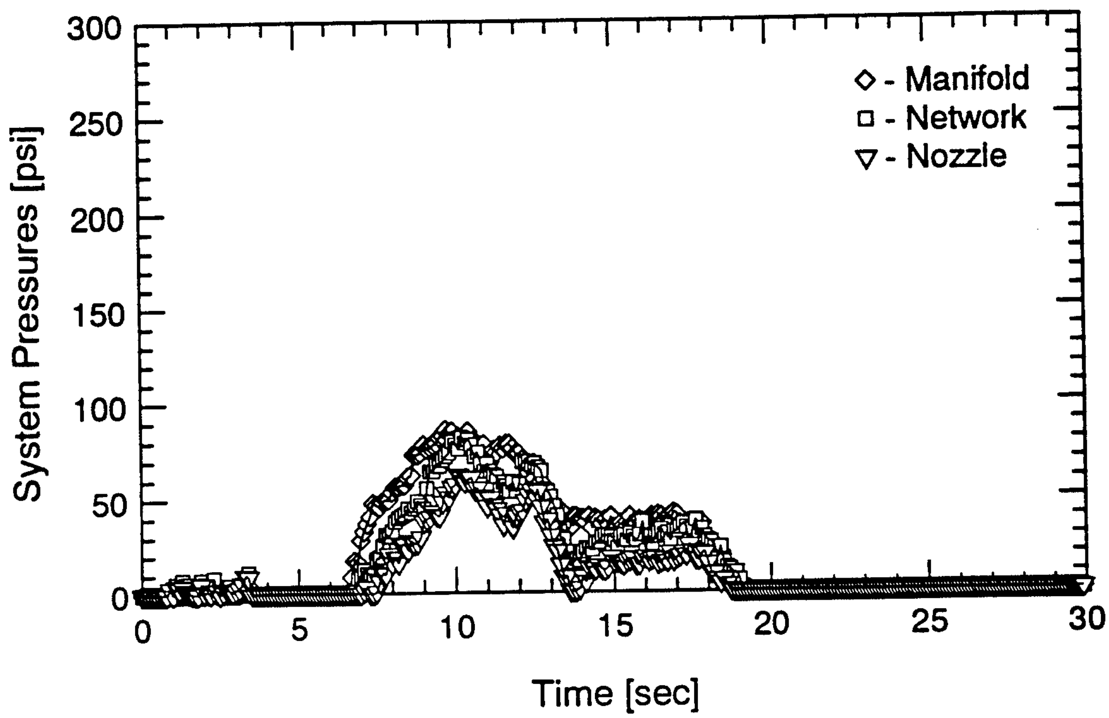
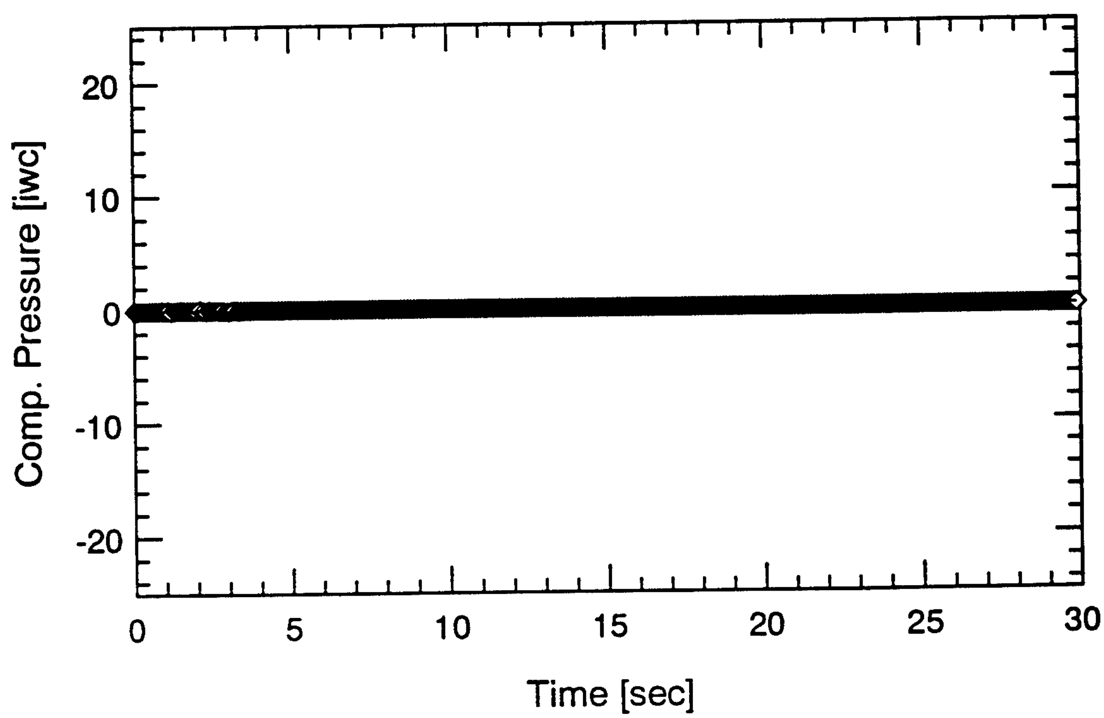
TEST #42



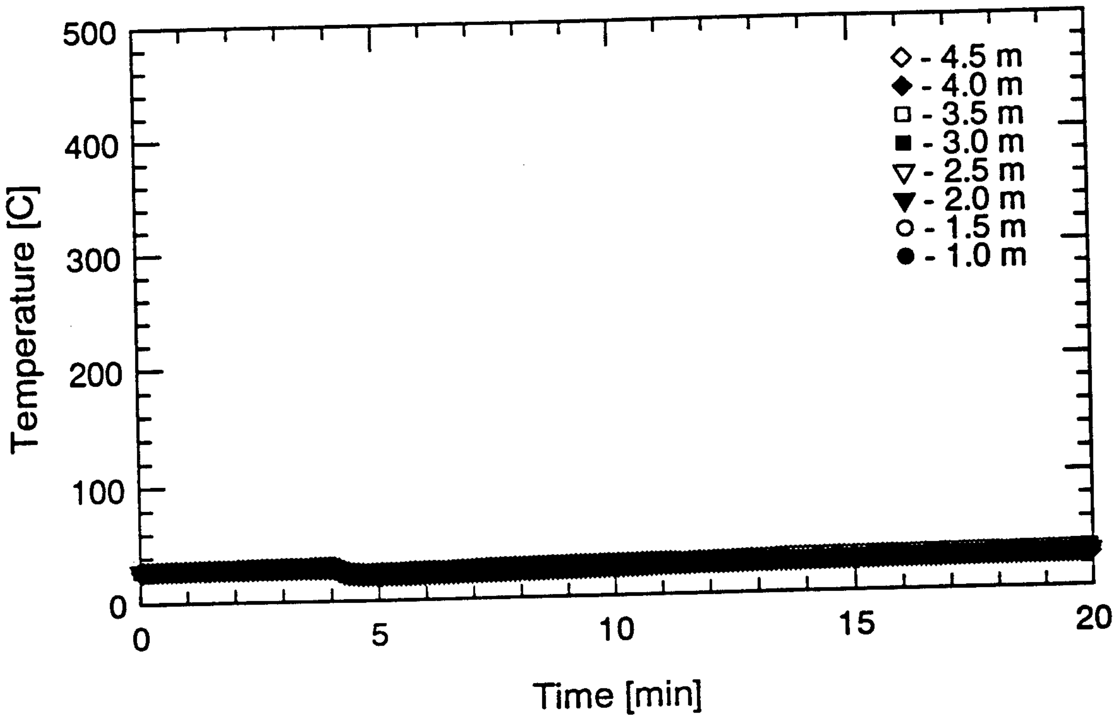



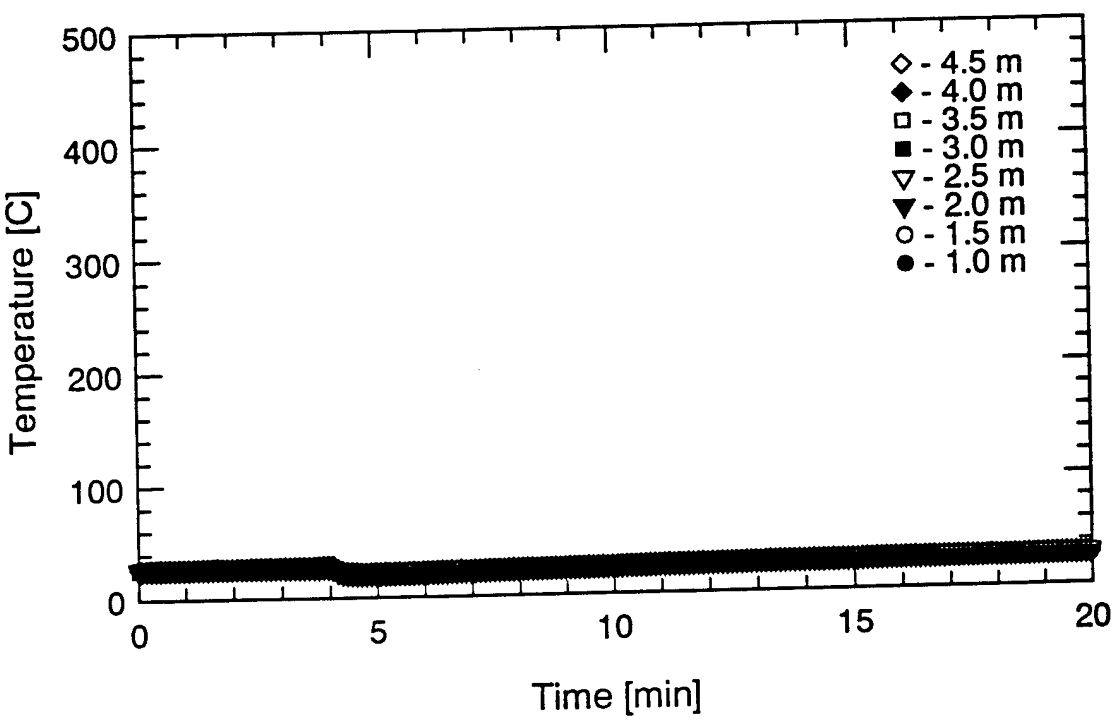

Agent and HF Concentrations
TEST #42



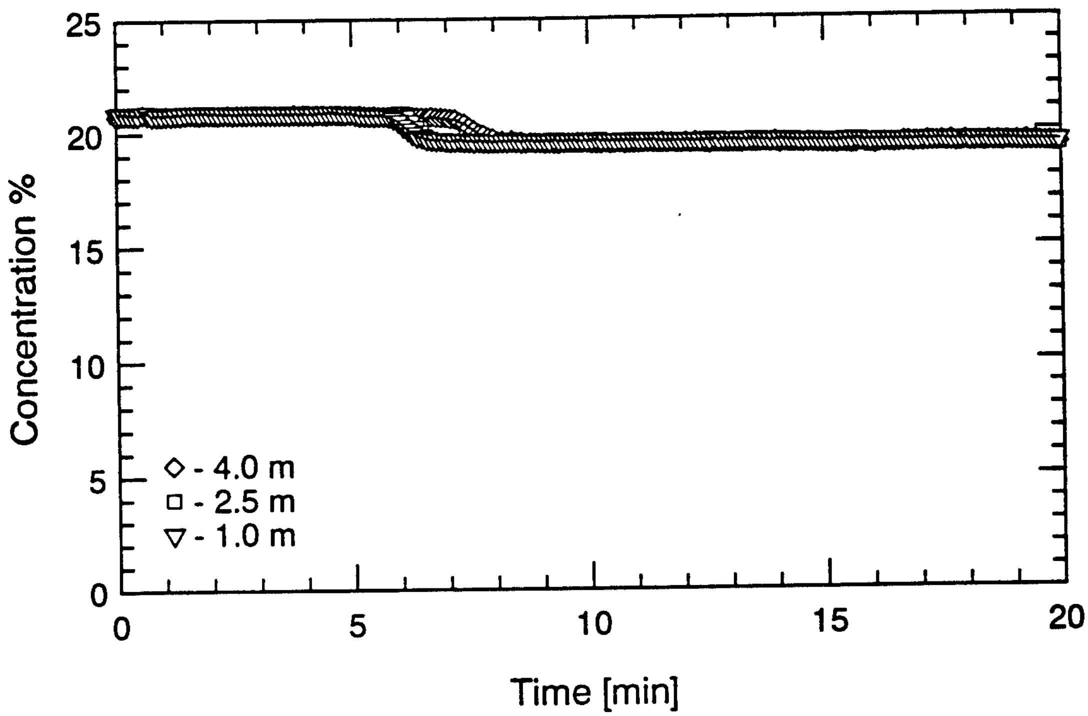



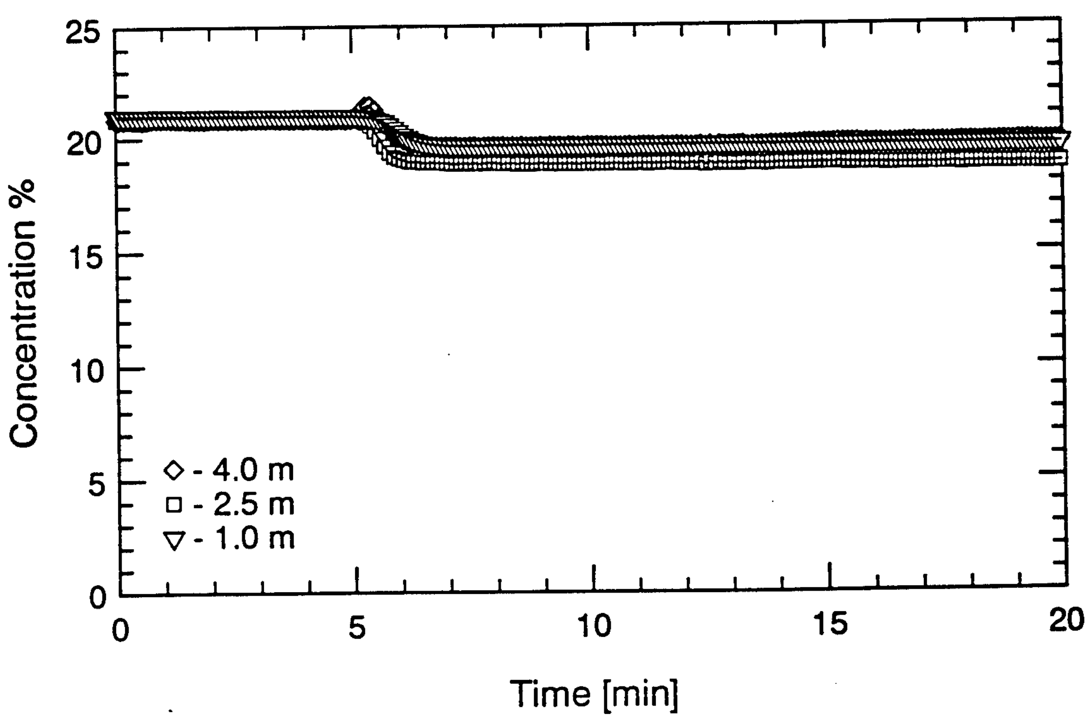

Pressure Measurements
TEST #42




Compartment Temperatures
TEST #43




Oxygen Concentrations
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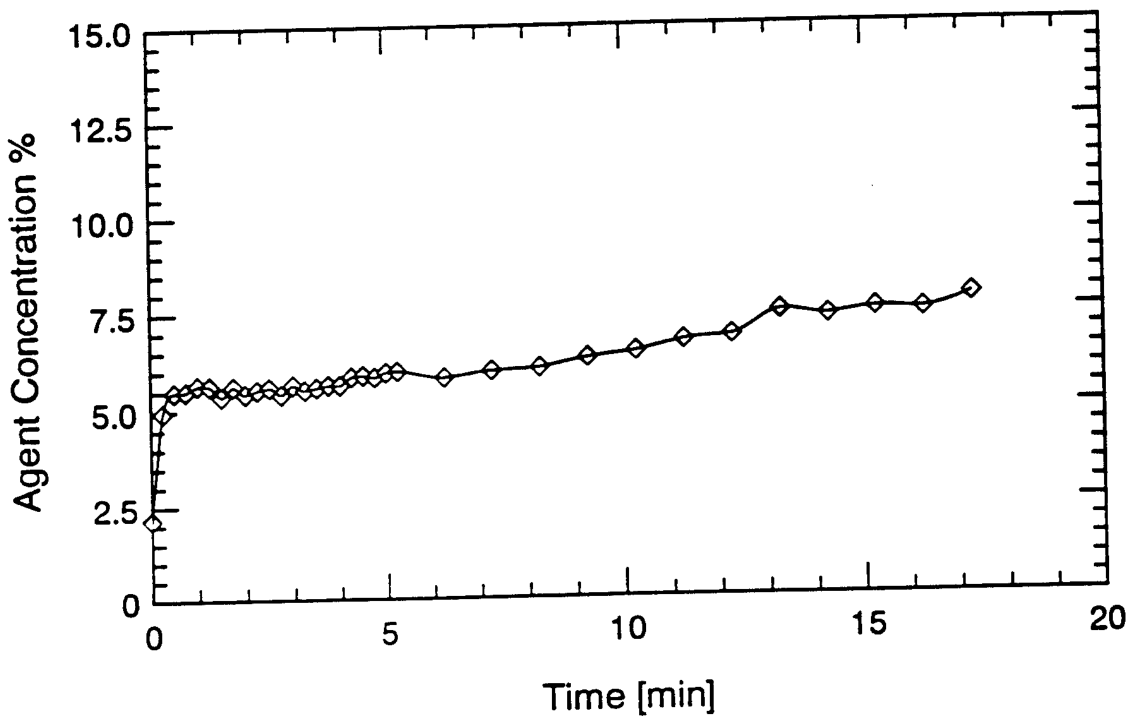
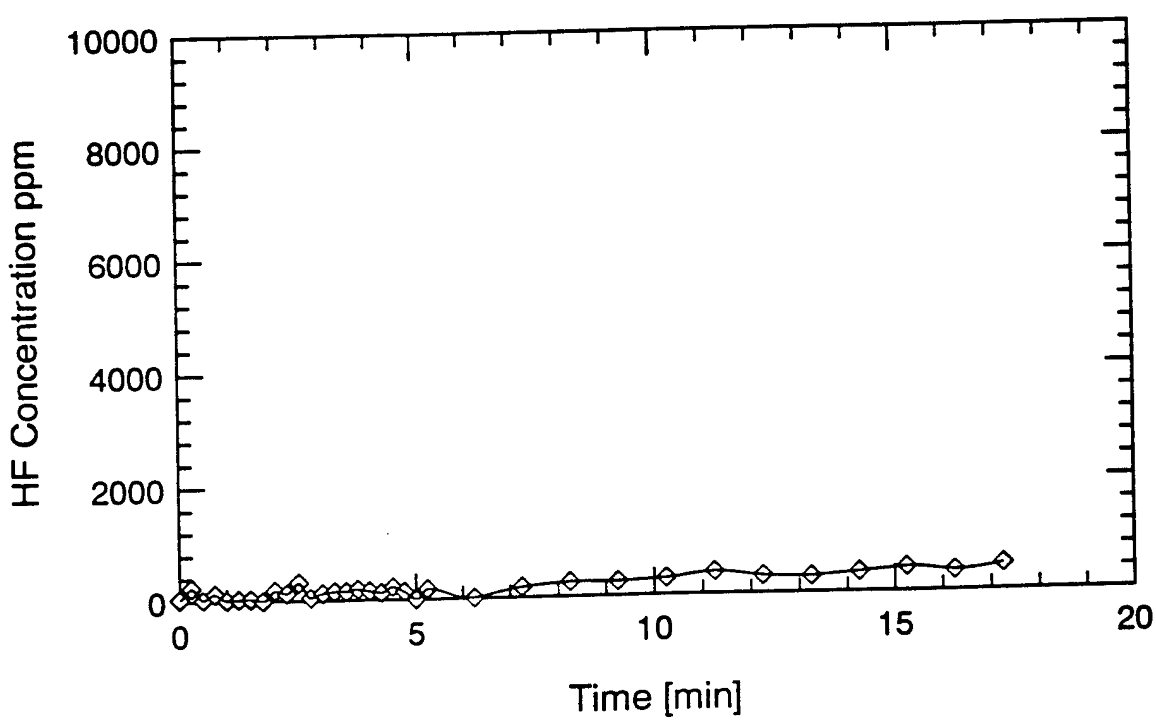
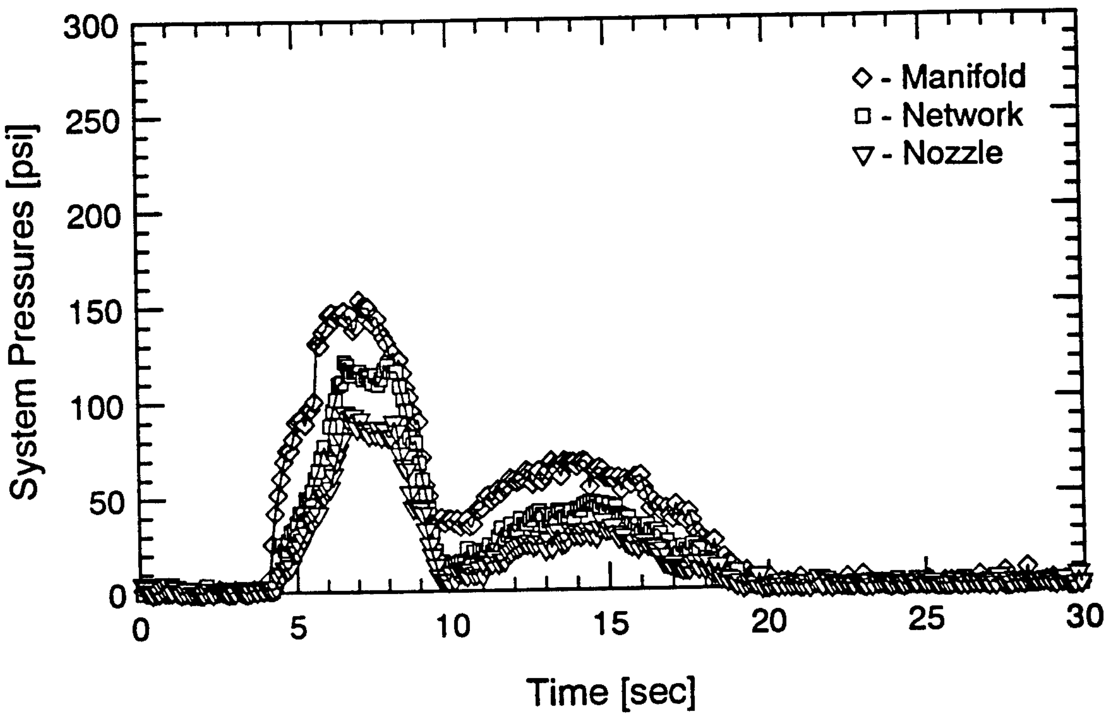
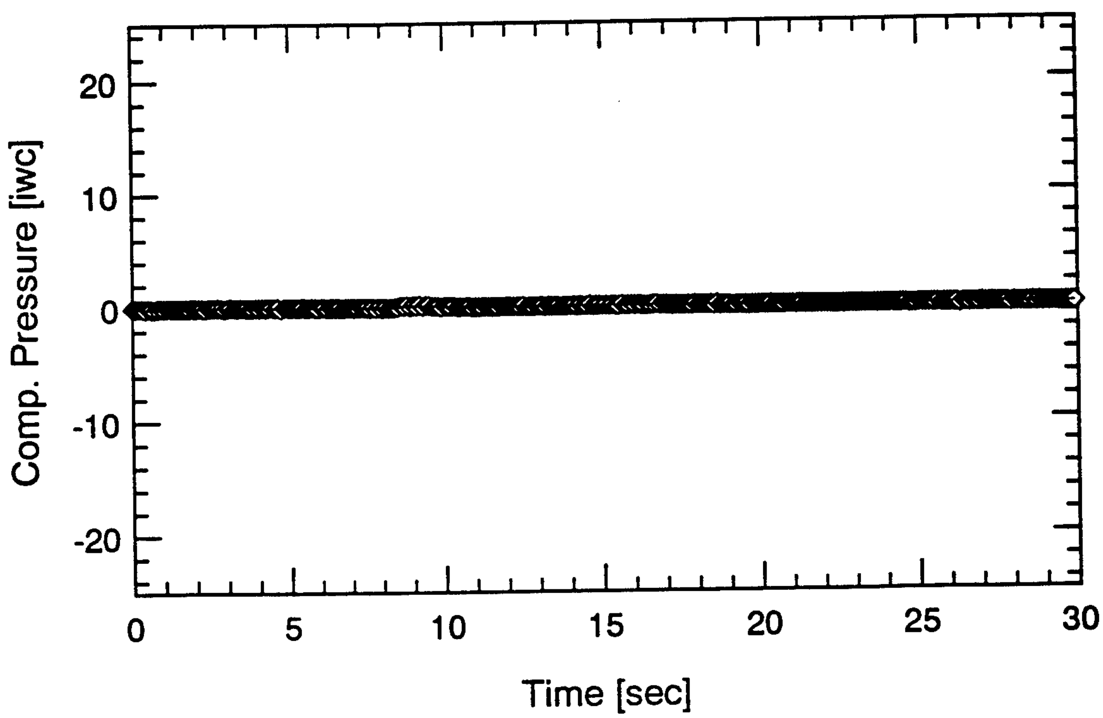


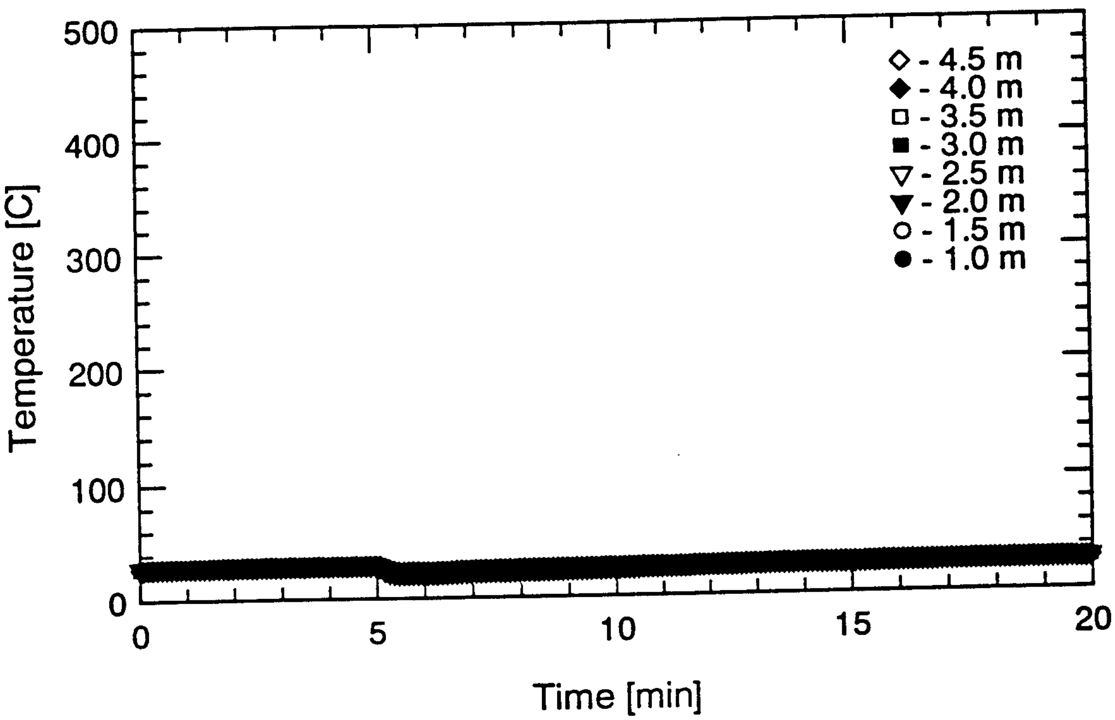



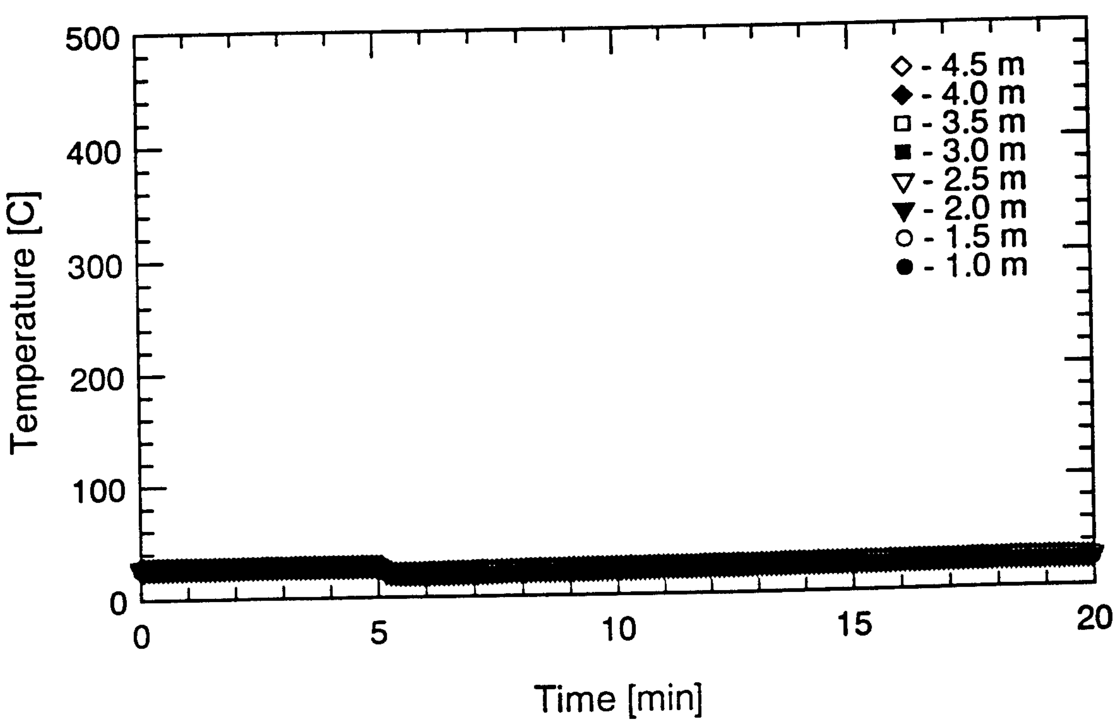

Agent and HF Concentrations
TEST #43




Pressure Measurements
TEST #43

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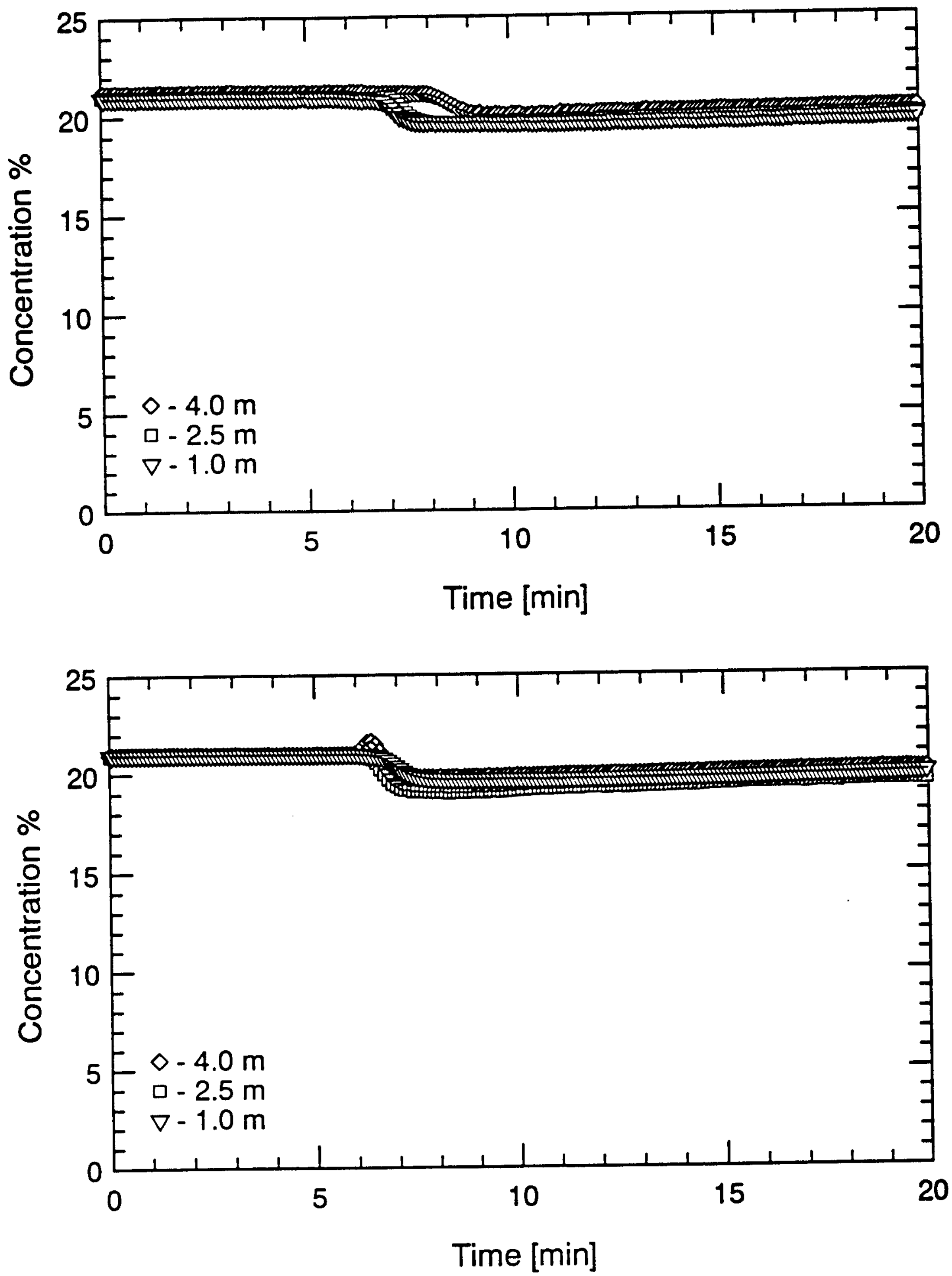


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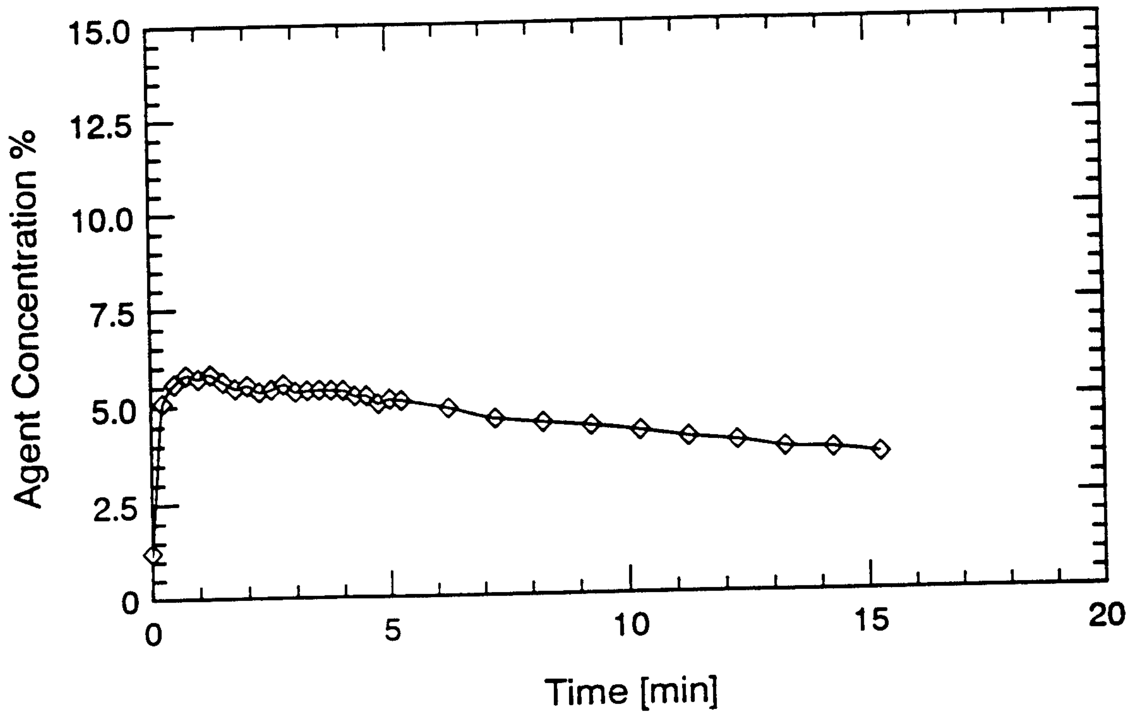
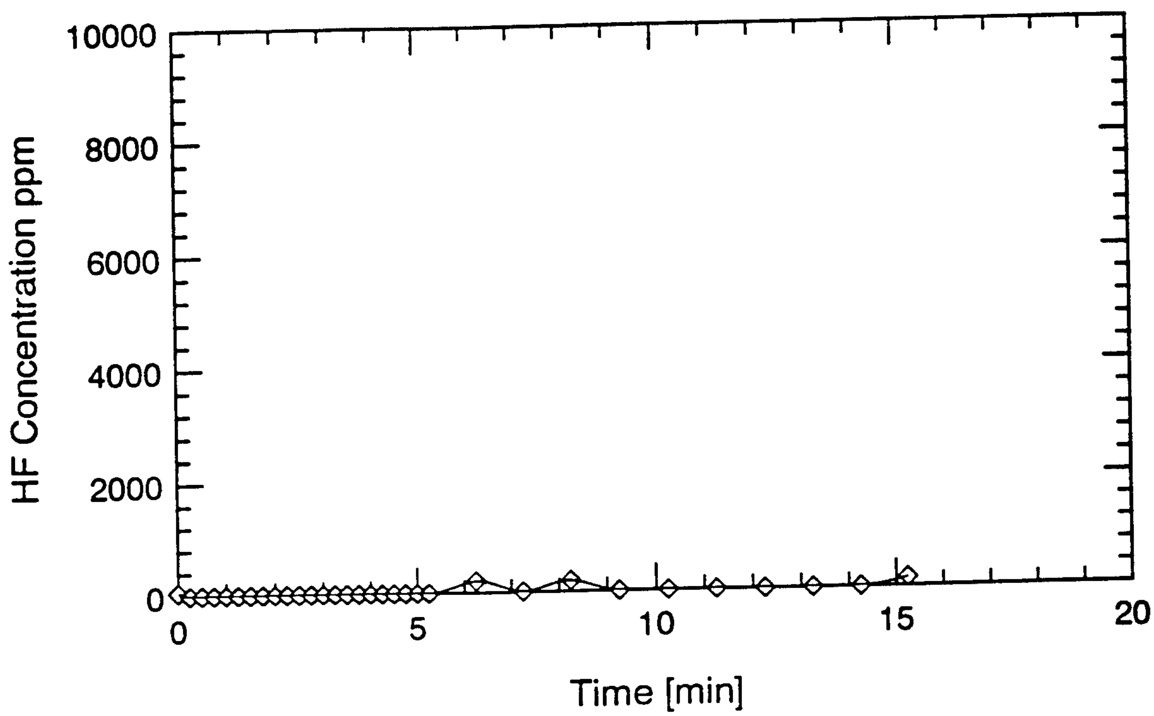
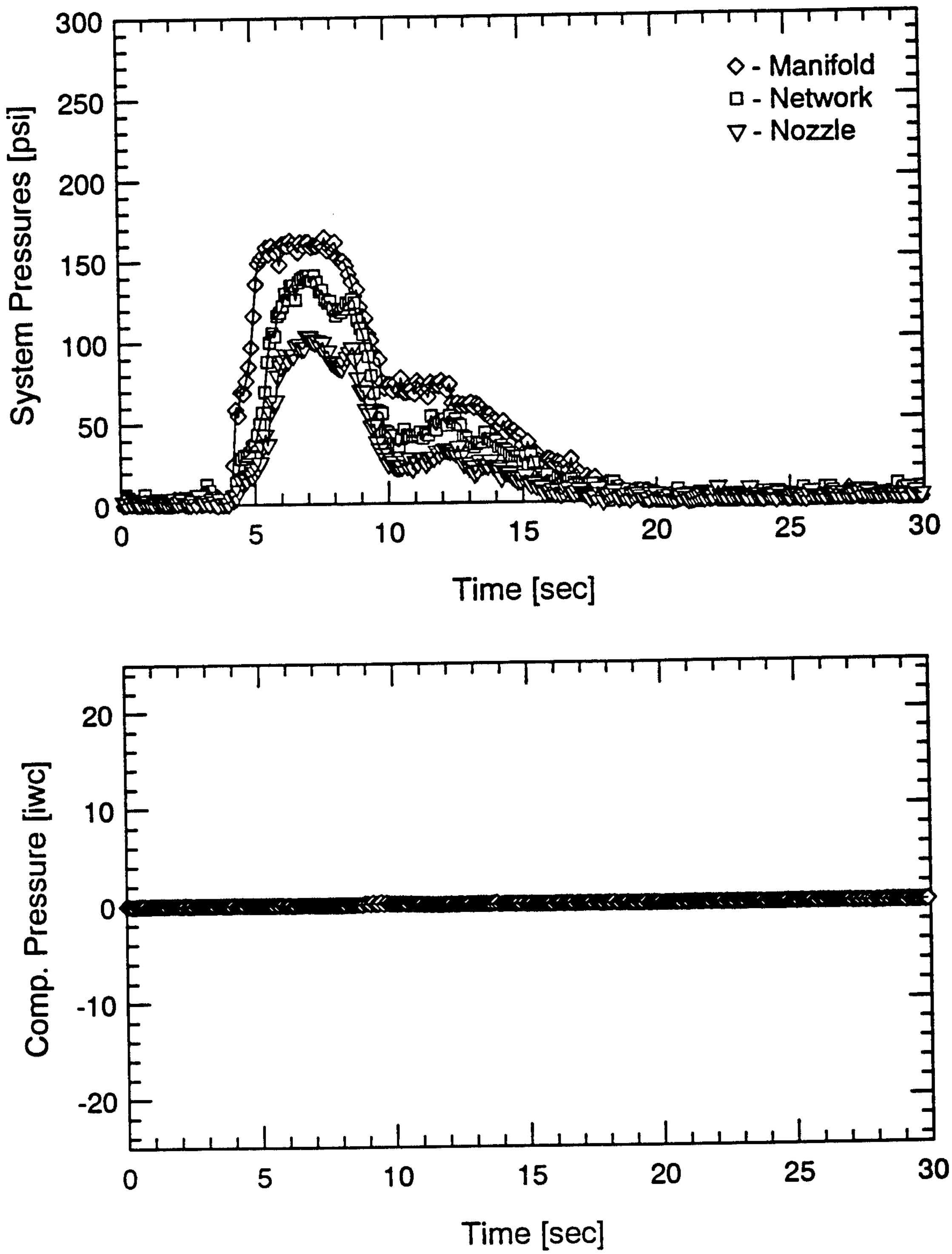
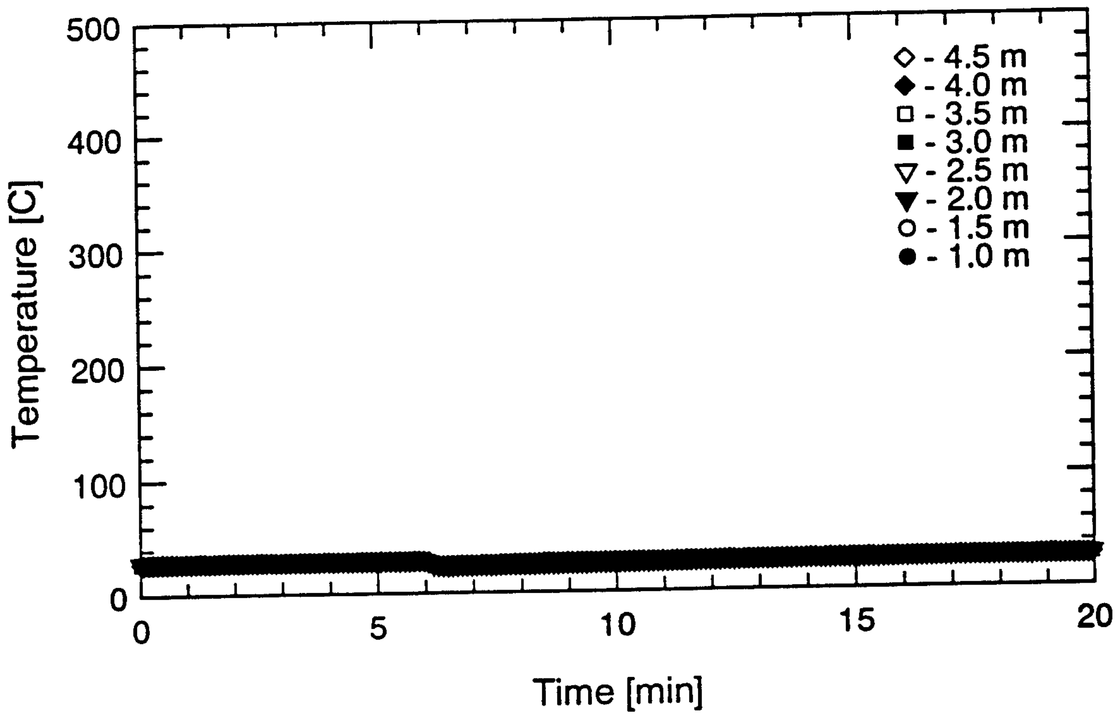


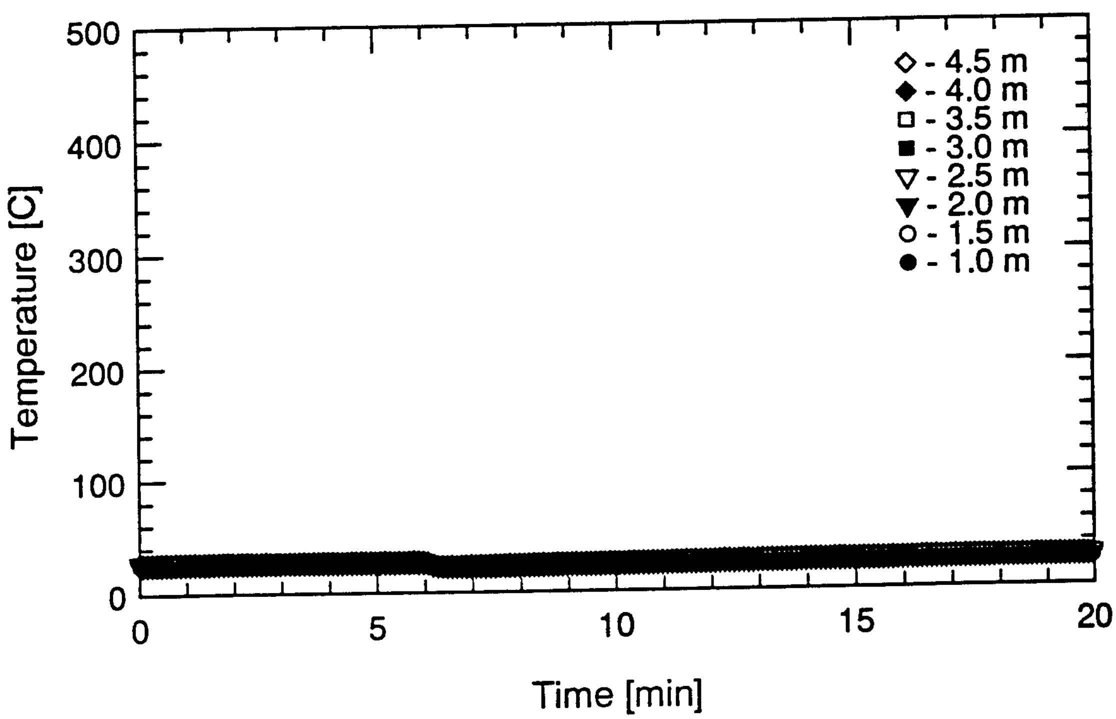




Agent and HF Concentrations
TEST #44




Pressure Measurements
TEST #44

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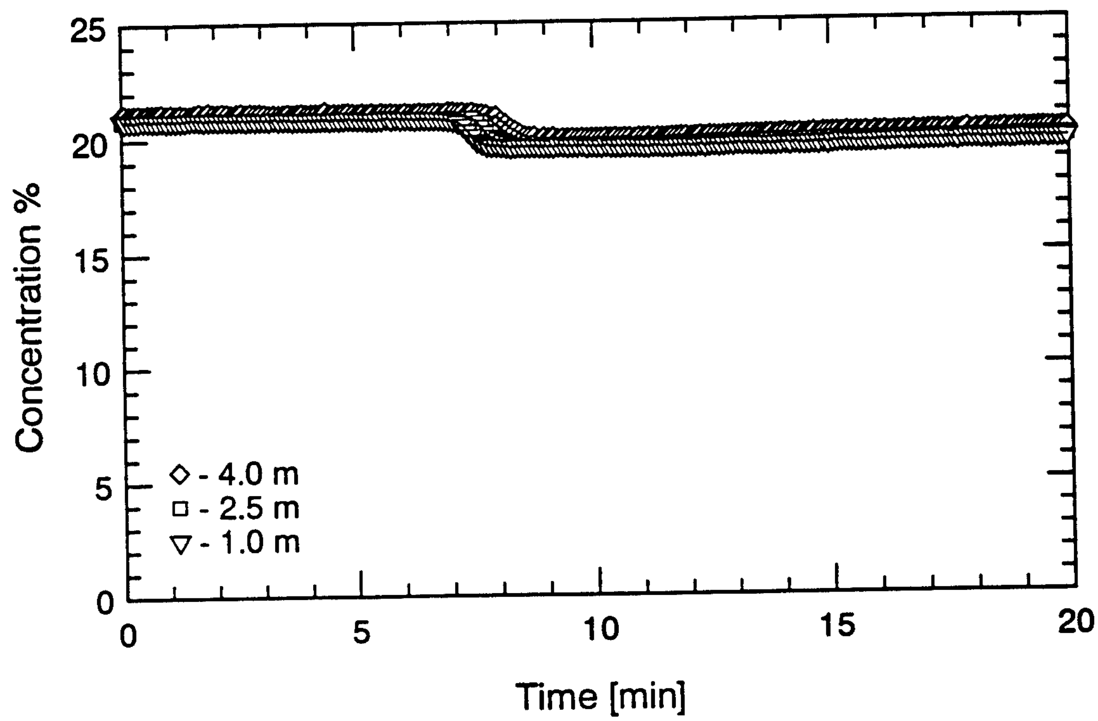


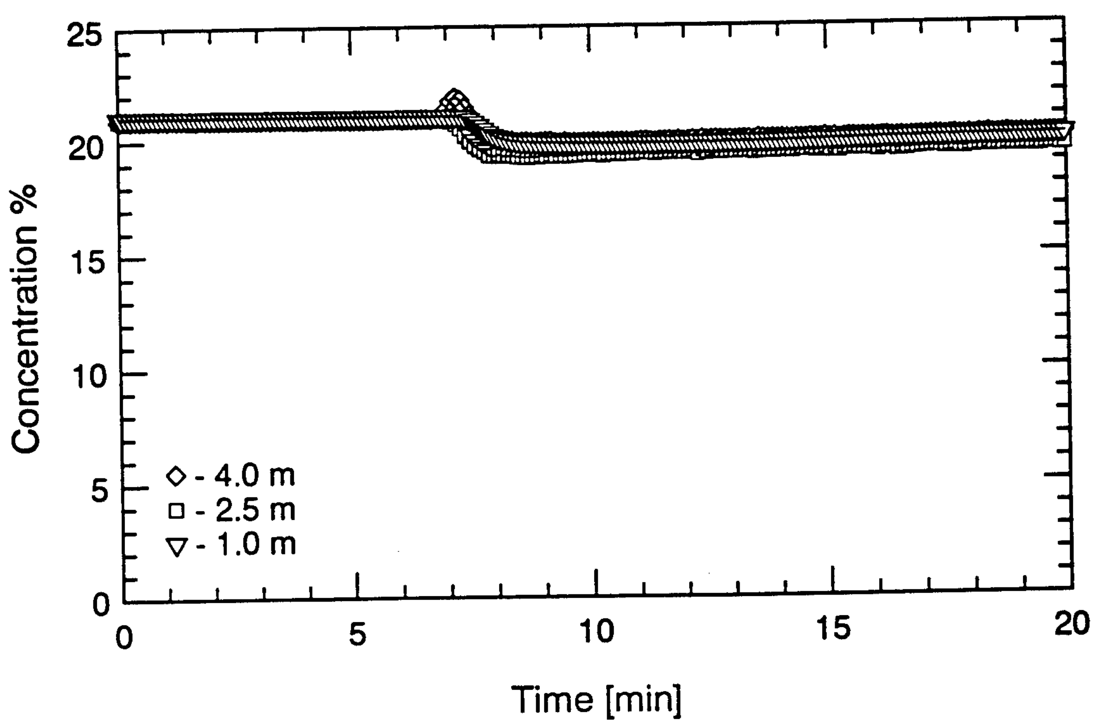


Oxygen Concentrations
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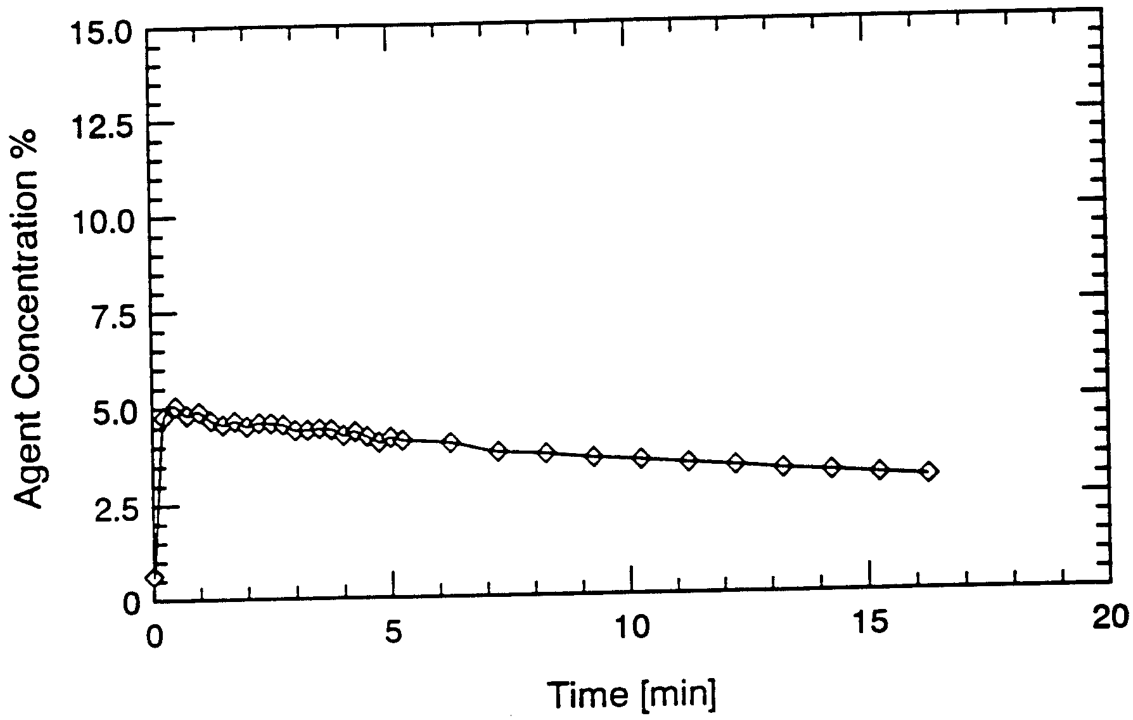


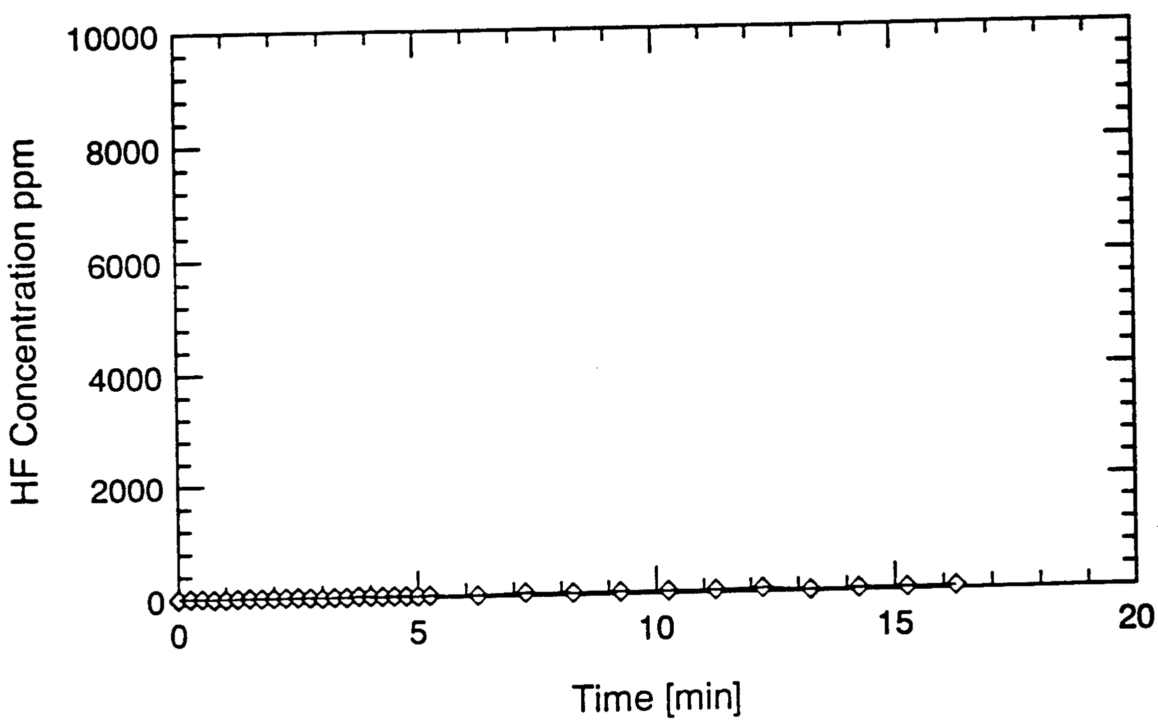


Agent and HF Concentrations
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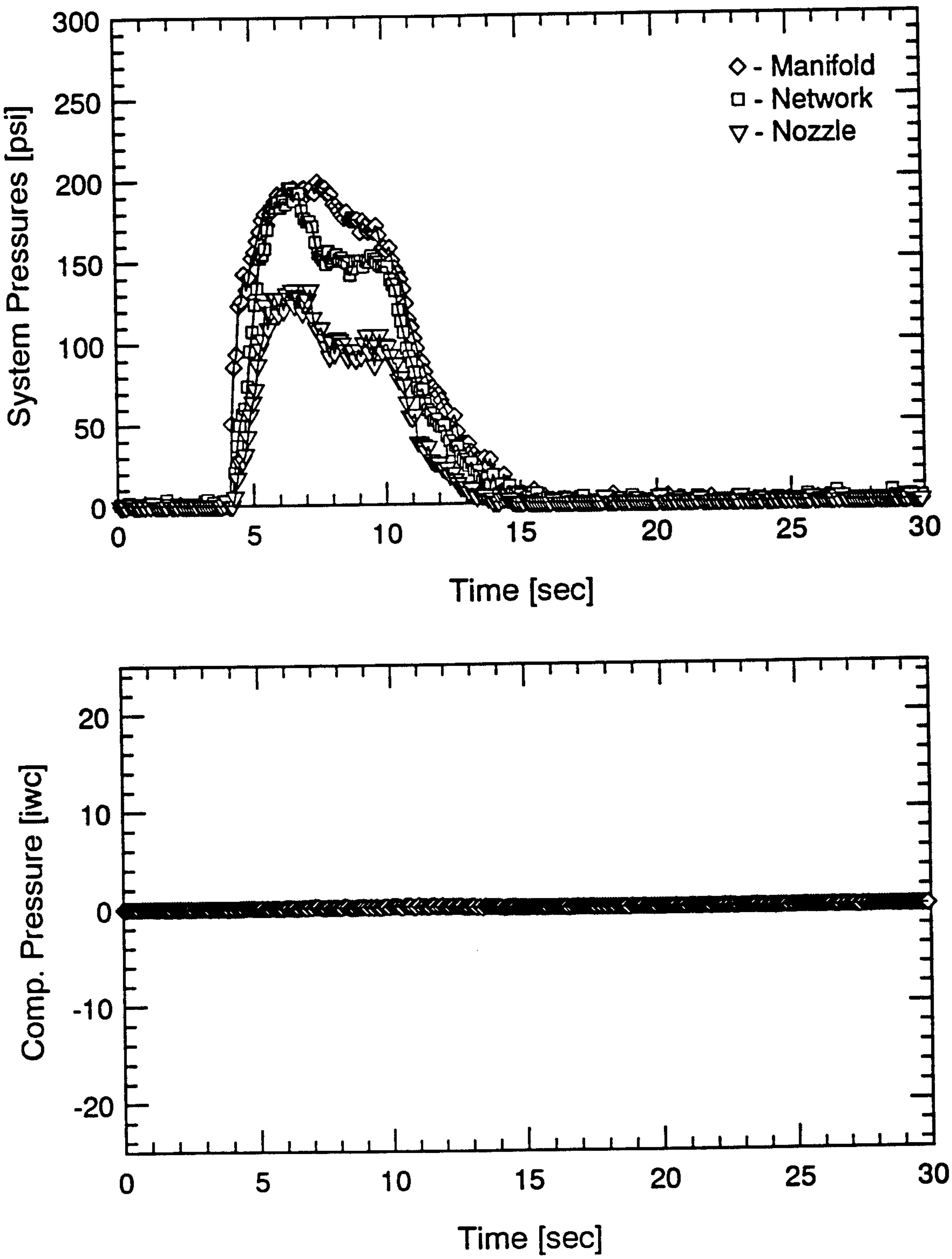
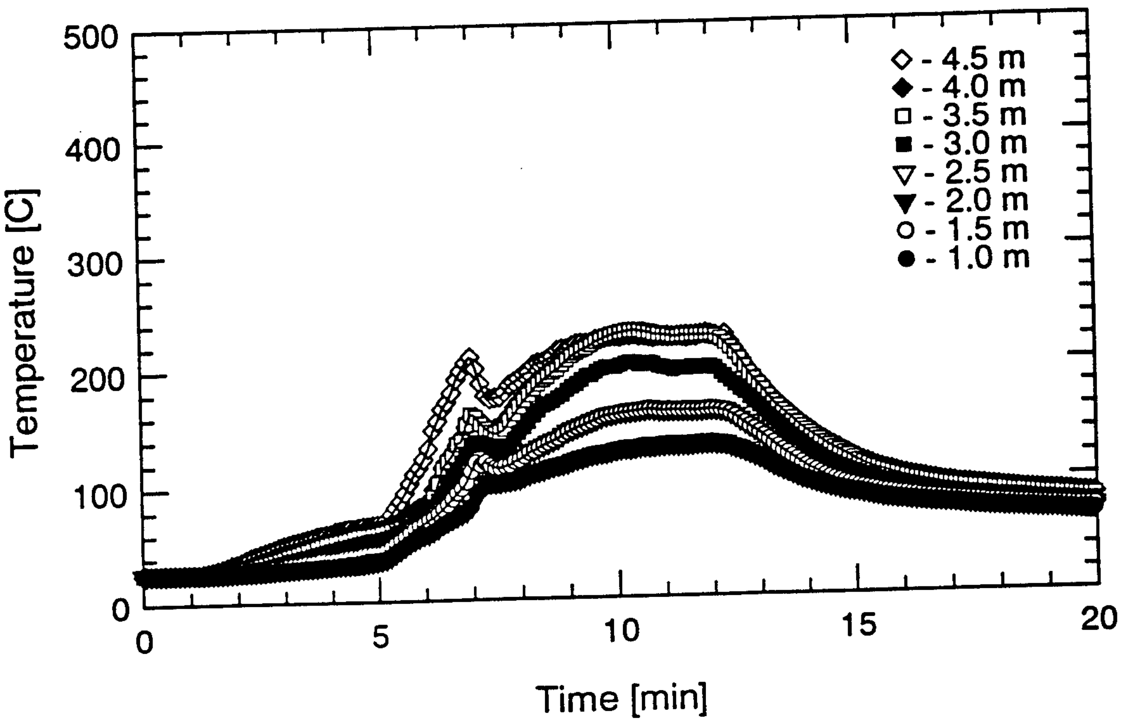
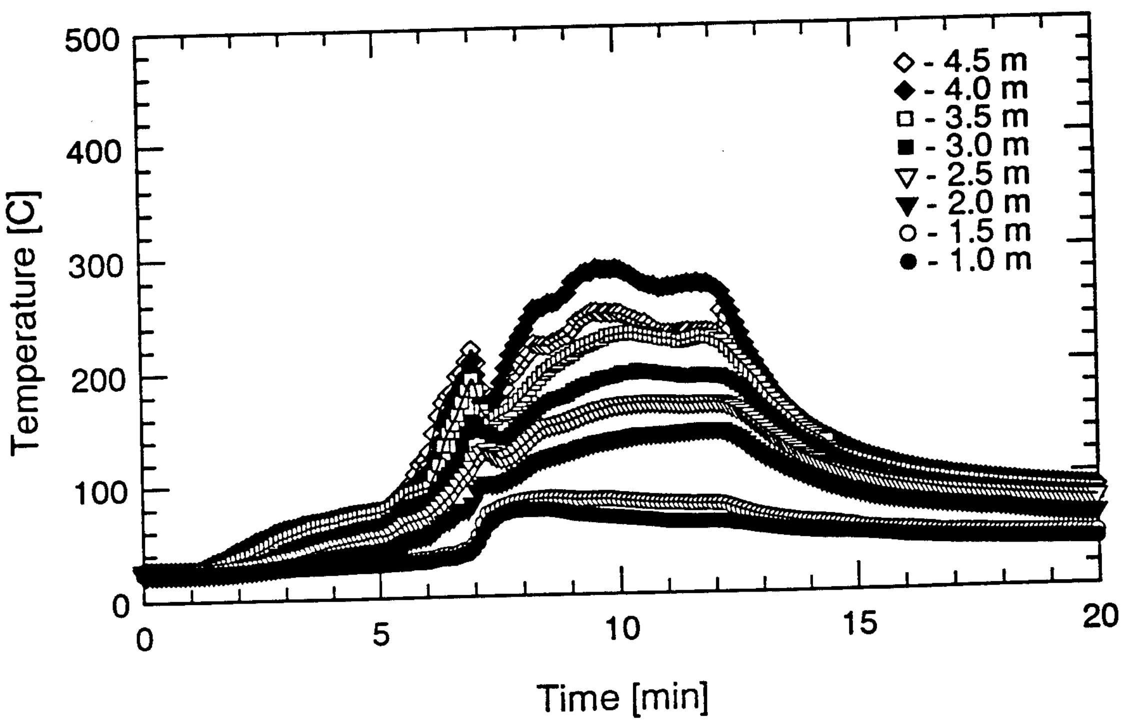
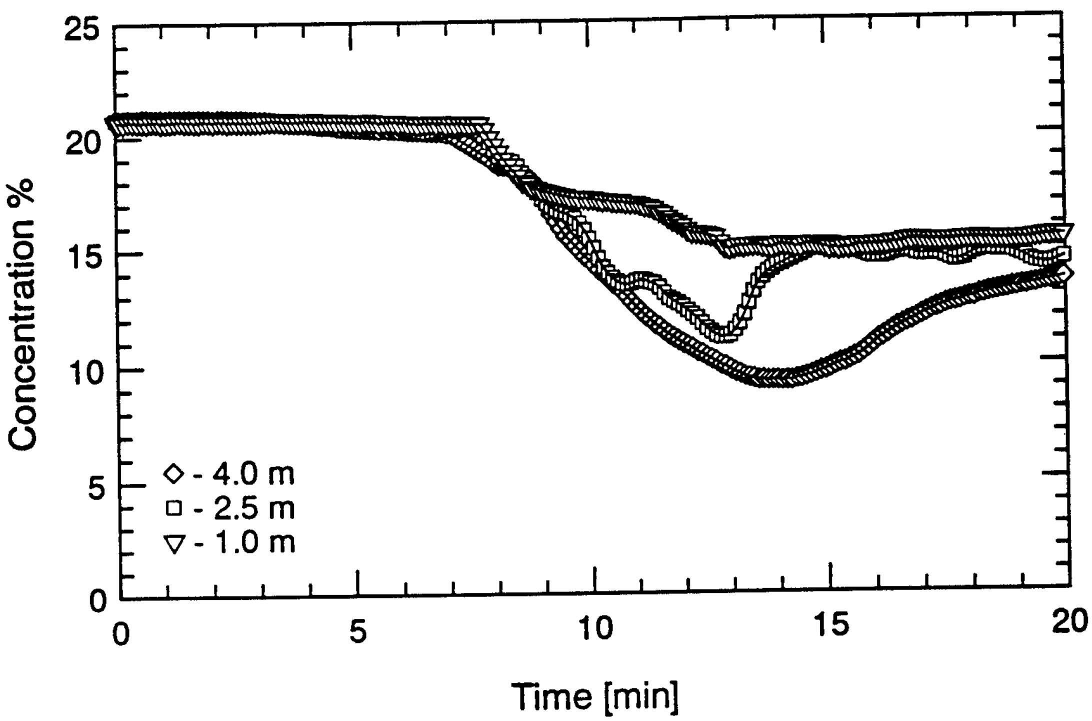


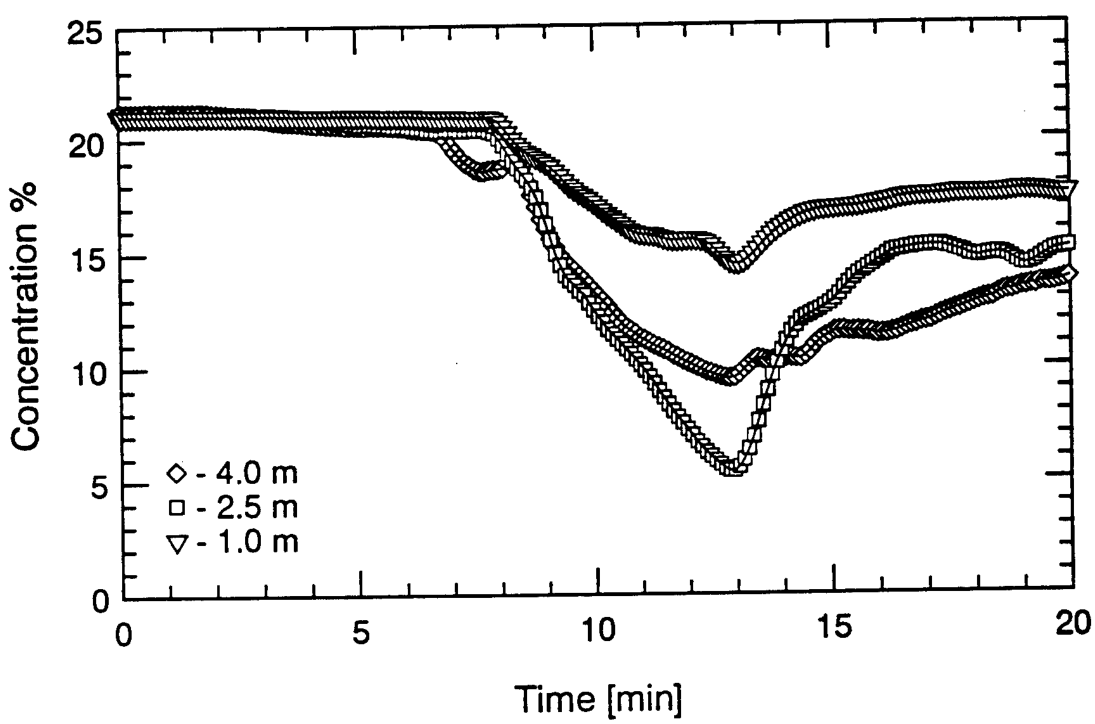

Pressure Measurements
TEST #45



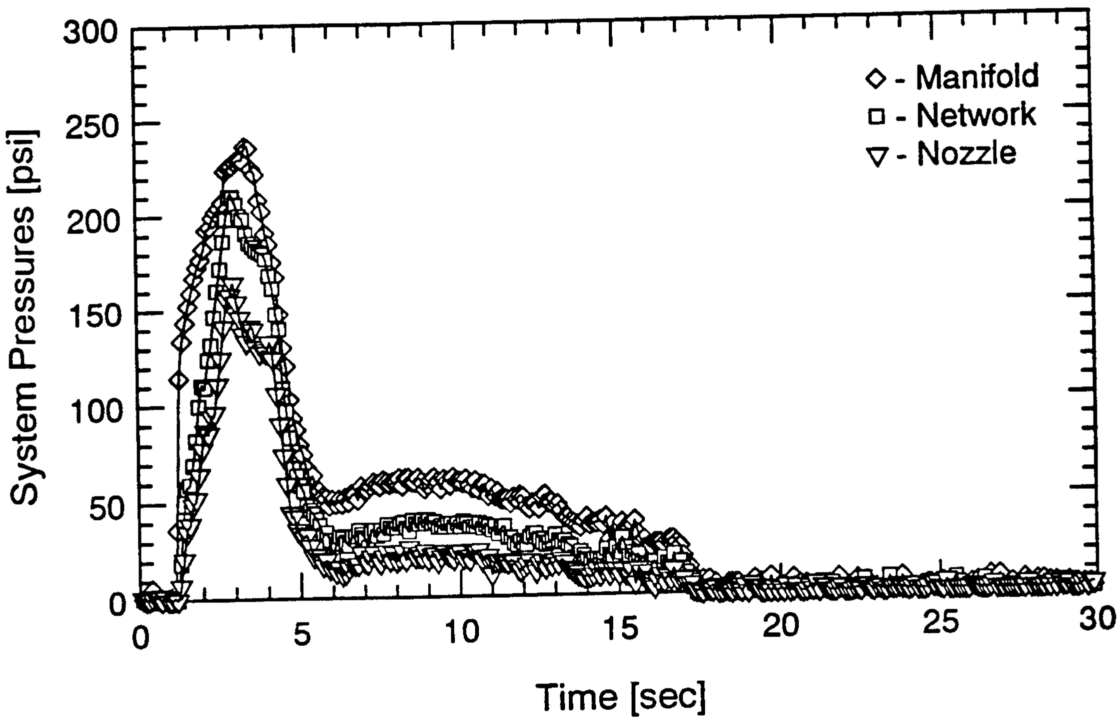



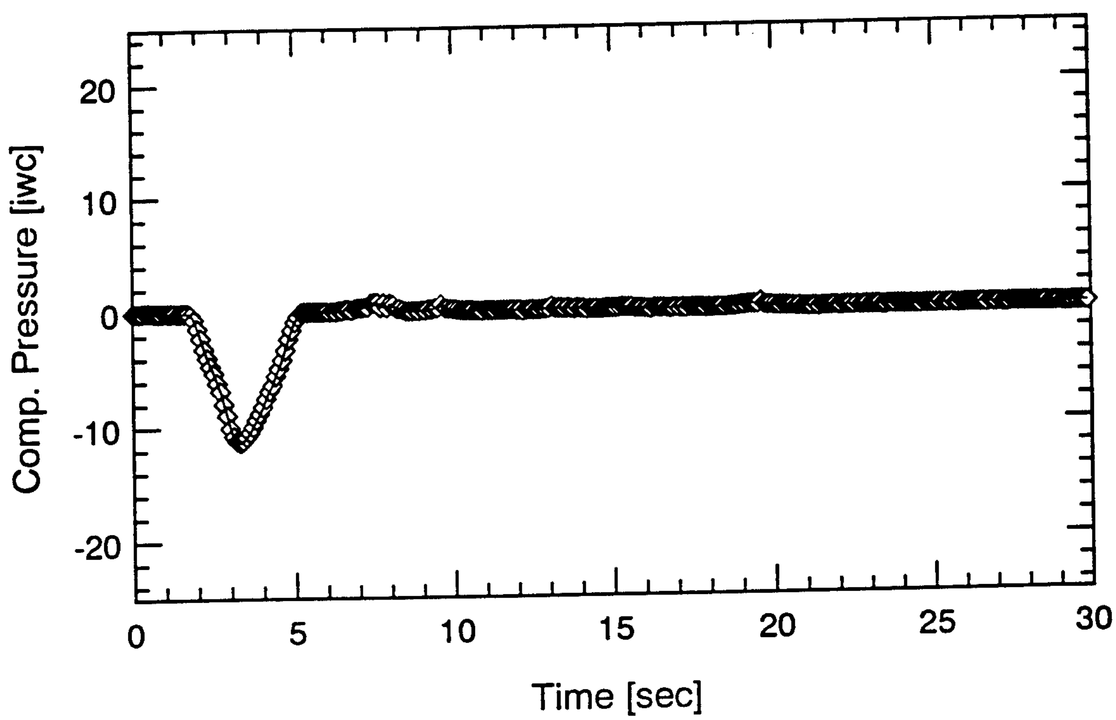

Compartment Temperatures
TEST #46




Oxygen Concentrations
TEST #46




Pressure Measurements
TEST #46

**INTERNATIONAL MARITIME ORGANIZATION**

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MSC/Circ.776
12 December 1996

Ref. T4/4.01

# GUIDELINES FOR THE APPROVAL OF EQUIVALENT FIXED GAS FIRE-EXTINGUISHING SYSTEMS, AS REFERRED TO IN SOLAS 74, FOR MACHINERY SPACES AND CARGO PUMP-ROOMS

1 The Maritime Safety Committee, at its sixty-seventh session (2 to 6 December 1996), approved Guidelines for the approval of equivalent fixed gas fire-extinguishing systems, as referred to in SOLAS 74, for machinery spaces and cargo pump-rooms, as set out in the annex.

2 Member Governments are requested to apply the annexed guidelines when approving equivalent fixed gas fire-extinguishing systems for use in machinery spaces of category A and cargo pump-rooms.

***

## ANNEX

# GUIDELINES FOR THE APPROVAL OF EQUIVALENT FIXED GAS FIRE-EXTINGUISHING SYSTEMS, AS REFERRED TO IN SOLAS 74, FOR MACHINERY SPACES AND CARGO PUMP-ROOMS

**General**

1 Fixed gas fire-extinguishing systems for use in machinery spaces of category A and cargo pump-rooms equivalent to fire-extinguishing systems required by SOLAS regulations II-2/7 and II-2/63 should prove that they have the same reliability which has been identified as significant for the performance of fixed gas fire-extinguishing systems approved under the requirements of SOLAS regulation II-2/5. In addition, the system should be shown by test to have the capability of extinguishing a variety of fires that can occur in a ship's engine-room.

**Principal requirements**

2 All requirements of SOLAS Regulations II-2/5.1, 5.3.1, 5.3.2 to 5.3.3 except as modified by these guidelines, should apply.

3 The minimum extinguishing concentration should be determined by a cup burner test acceptable to the Administration. The design concentration should be at least 20 per cent above the minimum extinguishing concentration. These concentrations should be verified by full-scale testing described in the test method, as set out in the appendix.

4 For systems using halocarbon clean agents, 95 per cent of the design concentration should be discharged in 10 seconds or less. For inert gas systems, the discharge time should not exceed 120 seconds for 85 per cent of the design concentration.

5 The quantity of extinguishing agent for the protected space should be calculated using the design concentration based on the gross volume of the protected space including the casing. If the quantity of extinguishing agent when applied to the net volume of the protected space including casing exceeds the agent's LOAEL (Lowest Observed Adverse Effect Level), the quantity of agent should be reduced, but not below the agent's design concentration based on net volume.

6 No fire suppression agent should be used which is carcinogenic, mutagenic, or teratogenic at concentrations expected during use. No agent should be used in concentrations greater than the cardiac sensitization NOAEL (No Observed Adverse Effect Level), nor the ALC (Approximate Lethal Concentration), without the use of controls as provided in SOLAS 74 regulation II-2/5.1 and 5.3. In no case should an agent be used above its LOAEL (Lowest Observed Adverse Effect Level).

7 The system and its components should be suitably designed to withstand ambient temperature changes, vibration, humidity, shock, impact, clogging, and corrosion normally encountered in machinery spaces or cargo pump-rooms in ships.

8 The system and its components should be designed and installed in accordance with international standards acceptable to the Organization[1] and manufactured and tested to the satisfaction of the Administration. As a minimum, the design and installation standards should cover the following elements:

.1 safety:

toxicity;
noise, nozzle discharge; and
decomposition products;

.2 storage container design and arrangement:

strength requirements;
maximum/minimum fill density, operating temperature range;
pressure and weight indication;
pressure relief; and
agent identification and lethal requirements;

.3 agent supply, quantity, quality standards;

.4 pipe and fittings:

strength, material, properties, fire resistance; and
cleaning requirements;

.5 valves:

testing requirements;
corrosion resistance; and
elastomer compatibility;

.6 nozzles:

height and area testing requirements; and
corrosion and elevated temperature resistance;

.7 actuation and control systems:

testing requirements; and
backup power requirements;

[1]Until international standards are developed, national standards acceptable to the Administration should be used. Available national standards include, e.g., Standards Australia, United Kingdom and NFPA 2001.

.8 alarms and indicators:

predischarge alarm, agent discharge alarms as time delays;
abort switches;
supervisory circuit requirements; and
warning signs and audible and visual alarms should be located outside each entry to the relevant space as appropriate;

.9 agent flow calculation:

approval and testing of design calculation method; and
fitting losses and/or equivalent length;

.10 enclosure integrity and leakage requirements:

enclosure leakage;
openings; and
mechanical ventilation interlocks;

.11 design concentration requirements, total flooding quantity;

.12 discharge time; and

.13 inspection, maintenance, and testing requirements.

9 The nozzle type, maximum nozzle spacing, maximum height and minimum nozzle pressure should be within limits tested to provide fire extinction per the proposed test method.

10 Provisions should be made to ensure that escape routes which are exposed to leakage from the protected space are not rendered hazardous during or after discharge of the agent. Control stations and other locations that require manning during a fire situation should have provisions to keep HF and HCl below 5 ppm at that location. The concentrations of other products should be kept below concentrations considered hazardous for the required duration of exposure.

11 Agent containers may be stored within a protected machinery space if the containers are distributed throughout the space and the provisions of SOLAS regulation II-2/5.3.3 are met. The arrangement of containers and electrical circuits and piping essential for the release of any system should be such that in the event of damage to any one power release line through fire or explosion in the protected space, i.e. a single fault concept, at least five-sixths of the fire-extinguishing charge as required by paragraph 5 of this annex can still be discharged having regard to the requirement for uniform distribution of medium throughout the space. The arrangements in respect of systems for spaces requiring less than 6 containers should be to the satisfaction of the Administration.

12 A minimum agent hold time of 15 minutes should be provided.

13 The release of an extinguishing agent may produce significant over and under pressurization in the protected space. Measures to limit the induced pressures to acceptable limits should be provided.

14 For all ships, the fire-extinguishing system design manual should address recommended procedures for the control of products of agent decomposition. The performance of fire-extinguishing arrangements on passenger ships should not present health hazards from decomposed extinguishing agents, e.g., on passenger ships, the decomposition products should not be discharged in the vicinity of muster (assembly) stations.

# APPENDIX

# TEST METHOD FOR FIRE TESTING OF FIXED GAS FIRE-EXTINGUISHING SYSTEMS

## 1 Scope

1.1 This test method is intended for evaluating the extinguishing effectiveness of fixed gas fire-extinguishing systems for the protection of machinery spaces of category A and cargo pump-rooms.

1.2 Fire-extinguishing systems presently covered in regulation II-2/5, of SOLAS 1974, as amended, are excluded.

1.3 The test method covers the minimum requirements for fire-extinguishing.

1.4 This test method is applicable to gases, liquefied gases and mixtures of gases. The test method is not valid for extinguishant gases mixed with compounds in solid or liquid state at ambient conditions.

1.5 The test programme has two objectives: (1) establishing the extinguishing effectiveness of a given agent at its tested concentration, and (2) establishing that the particular agent distribution system puts the agent into the enclosure in such a way as to fully flood the volume to achieve an extinguishing concentration at all points.

## 2 Sampling

The components to be tested should be supplied by the manufacturer together with design and installation criteria, operational instructions, drawings and technical data sufficient for the identification of the components.

## 3 Method of test

3.1 Principle

This test procedure enables the determination of the effectiveness of different gaseous agent extinguishing systems against spray fires, pool fires and class A fires.

3.2 Apparatus

3.2.1 Test room

The tests should be performed in 100 $m^2$ room, with no horizontal dimension less than 8 m, with a ceiling height of 5 m. The test room should be provided with a closable access door measuring approximately 4 $m^2$ in area. In addition, closable ventilation hatches measuring at least 6 $m^2$ in total area should be located in the ceiling.

3.2.2 Integrity of test enclosure

The test enclosure is to be nominally leak tight when doors and hatches are closed. The integrity of seals on doors, hatches, and other penetrations (e.g., instrumentation access ports) must be verified before each test.

3.2.3 Engine mock-up

.1 An engine mock-up of size (width x length x height) 1 m x 3 m x 3 m should be constructed of sheet steel with a nominal thickness of 5 mm. The mock-up should be fitted with two steel tubes diameter 0.3 m and 3 m length that simulate exhaust manifolds and a solid steel plate. At the top of the mock-up a 3 $m^2$ tray should be arranged. See figures 1, 2 and 3.

.2 A floor plate system 4 m x 6 m x 0.75 m high shall surround the mock-up. Provision shall be made for placement of the fuel trays, described in table 1, and located as described in table 2.

3.2.4 Instrumentation

Instrumentation for the continuous measurement and recording of test conditions should be employed. The following measurements should be made:

.1 temperature at three vertical positions (e.g., 1, 2.5, and 4.5 m)

.2 enclosure pressure

.3 gas sampling and analysis, at mid-room height, for oxygen, carbon dioxide, carbon monoxide, and relevant halogen acid products, e.g., hydrogen iodide, hydrofluoric acid, hydrochloric acid

.4 means of determining flame-out indicators

.5 fuel nozzle pressure in the case of spray fire

.6 fuel flow rate in the case of spray fires

.7 discharge nozzle pressure

3.2.5 Nozzles

3.2.5.1 For test purposes, nozzles should be located within 1 m of the ceiling.

3.2.5.2 If more than one nozzle is used they should be symmetrically located.

3.2.6 Enclosure temperature

3.2.6.1 The ambient temperature of the test enclosure at the start of the test should be noted and serve as the basis for calculating the concentration that the agent would be expected to achieve at that temperature and with that agent weight applied in the test volume.

3.3 Test fires and programme

3.3.1 Fire types

The test programme, as described in table 3, should employ test fires as described in table 1.

Table 1
Parameters of Test Fires

| Fire | Type | Fuel | Fire Size, MW | Remarks |
|---|---|---|---|---|
| A | 76 - 100 mm ID Can | Heptane | 0.0012 to 0.002 | Tell tale |
| B | 0.25 $m^2$ Tray | Heptane | 0.35 | |
| C | 2 $m^2$ Tray | Diesel /Fuel Oil | 3 | |
| D | 4 $m^2$ Tray | Diesel /Fuel Oil | 6 | |
| E | Low pressure spray | Heptane 0.16 ± 0.01 kg/s | 5.8 | |
| F | Low pressure, low flow spray | Heptane 0.03 ± 0.005 kg/s | 1.1 | |
| G | High pressure spray | Diesel /Fuel Oil 0.05 ± 0.002 kg/s | 1.8 | |
| H | Wood Crib | Spruce or Fir | 0.3 | See Note 2 |
| I | 0.10 $m^2$ tray | Heptane | 0.14 | |

Notes to table 1:

1 Diesel /Fuel Oil means light diesel or commercial fuel oil.

2 The wood crib should be substantially the same as described in ISO/TC 21/SC5/WG 8 ISO Draft International Standard , *Gaseous fire extinguishing systems, Part 1: General Requirements*. The crib should consist of six, trade size 50 mm x 50 mm by 450 mm long, kiln dried spruce or fir lumber having a moisture content between 9 and 13 per cent. The members should be placed in 4 alternate layers at right angles to one another. Members should be evenly spaced forming a square structure.

Achieve ignition of the crib by burning commercial grade heptane in a square steel tray 0.25 $m^2$ in area. During the pre-burn period the crib should be placed centrally above the top of the tray a distance of 300 to 600 mm.

Table 2
Spray fire test parameters

| Fire type | Low pressure(E) | Low pressure, Low flow(F) | High pressure(G) |
|---|---|---|---|
| Spray nozzle | Wide spray angle (120 to 125°) full cone type | Wide spray angle (80°) full cone type | Standard angle (at 6 Bar) full cone type |
| Nominal fuel pressure | 8 Bar | 8.5 Bar | 150 Bar |
| Fuel flow | 0.16 ± 0.01 kg/s | 0.03 ± 0.005 kg/s | 0.050 ± 0.002 kg/s |
| Fuel temperature | 20 ± 5°C | 20 ± 5°C | 20 ± 5°C |
| Nominal heat release rate | 5.8 ± 0.6 MW | 1.1 ± 0.1 MW | 1.8 ± 0.2 MW |

3.3.2 Test programme

The fire test programme should employ test fires singly or in combination, as outlined in table 3.

Table 3
Test Programme

| Test No. | Fire Combinations (See Table 1) |
|---|---|
| 1 | A: Tell tales, 8 corners. See note 1. |
| 2-a<br><br>See Note 2 | B: 0.25 $m^2$ heptane tray under engine mockup<br>E: Horizontal LP spray directed at 15-25 mm rod 0.5 m away<br>G: HP diesel/fuel oil spray on top of engine mock-up<br><br>Total Fire Load: 7.95 MW |
| 2-b<br><br>See Note 2 | B: 0.25 $m^2$ heptane tray under mock-up<br>I: 0.10 $m^2$ heptane tray on deck plate located below solid steel obstruction plate<br><br>Total Fire Load: 0.49 MW |
| 3 | C: 2 $m^2$ diesel/fuel oil tray on deck plate located below solid steel obstruction plate<br>H: Wood crib positioned as in Figure 1<br>F: Low pressure, low flow horizontal spray - concealed - with impingement on inside of engine mock-up wall.<br><br>Total Fire Load: 4.4 MW |
| 4 | D: 4 $m^2$ Diesel tray under engine mock-up<br><br>Total Fire Load: 6 MW |

Note to table 3:

1 Tell-tale fire cans should be located as follows:

(a) in upper corners of enclosure 150 mm below ceiling and 50 mm from each wall;
(b) in corners on floors 50 mm from walls.

2 Test 2-a is for use in evaluating extinguishing systems having discharge times of 10 seconds or less.

Test 2-b is for use in evaluating extinguishing systems having discharge times greater than 10 seconds.

3.3.2.1 All applicable tests of table 3 should be conducted for every new fire extinguishant gas, or mixture of gases.

3.3.2.2 Only Test 1 is required to evaluate new nozzles and related distribution system equipment (hardware) for systems employing fire extinguishants that have successfully completed the requirements of 3.3.2.1. Test 1 should be conducted to establish and verify the manufacturer's minimum nozzle design pressure.

3.4 Extinguishing system

3.4.1 System installation

The extinguishing system should be installed according to the manufacturer's design and installation instructions. The maximum vertical distance should be limited to 5 m.

3.4.2 Agent

3.4.2.1 Design concentration

The agent design concentration is that concentration (in volume per cent) required by the system designer for the fire protection application.

3.4.2.2 Test concentration

The concentration of agent to be used in the fire extinguishing tests should be the design concentration specified by the extinguishing system manufacturer, except for Test 1 which should be conducted at 83% of the manufacturer's recommended design concentration but in no case at less than the cup burner extinguishing concentration.

3.4.2.3 Quantity of agent

The quantity of agent to be used should be determined as follows:

3.4.2.3.1 Halogenated agents

$W = (V/S) \cdot C/(100 - C)$ where

W = agent mass, kg
V = volume of test enclosure, $m^3$
S = agent vapour specific volume at temperature and pressure of the test enclosure, $kg/m^3$
C = gaseous agent concentration, volume per cent

3.4.2.3.2 Inert gas agents

$$Q = V\,[294/(273 + T)] \cdot (P/1.013) \cdot \ln[100/(100 - C)] \quad \text{where}$$

Q = volume of inert gas, measured at 294 K and 1.013 bar, discharged, $m^3$
V = volume of test enclosure, $m^3$
T = test enclosure temperature, Celsius
P = test enclosure pressure, bar
C = gaseous agent concentration, volume per cent

3.5 Procedure

3.5.1 Fuel levels in trays

The trays used in the test should be filled with at least 30 mm fuel on a water base. Freeboard should be 150 ± 10 mm.

3.5.2 Fuel flow and pressure measurements

For spray fires, the fuel flow and pressure should be measured before and during each test.

3.5.3 Ventilation

3.5.3.1 Pre-burn period

During the pre-burn period the test enclosure should be well ventilated. The oxygen concentration, as measured at mid-room height, shall not be less than 20 volume per cent at the time of system discharge.

3.5.3.2 End of pre-burn period

Doors, ceiling hatches, and other ventilation openings should be closed at the end of the pre-burn period.

3.5.4 Duration of test

3.5.4.1 Pre-burn time

Fires should be ignited such that the following burning times occur before the start of agent discharge:

.1 sprays - 5 to 15 seconds
.2 trays - 2 minutes
.3 crib - 6 minutes

3.5.4.2 Discharge time

.1 halogenated agents should be discharged at a rate sufficient to achieve delivery of 95% of the minimum design quantity in 10 seconds or less.

.2 inert gas agents should be discharged at a rate sufficient to achieve 85% of the minimum design quantity in 120 seconds or less.

3.5.4.3 Soak time

After the end of agent discharge the test enclosure should be kept closed for 15 minutes.

3.5.5 Measurements and observations

3.5.5.1 Before test

.1 temperature of test enclosure, fuel and engine mock-up
.2 initial weights of agent containers
.3 verification of integrity agent distribution system and nozzles
.4 initial weight of wood crib

3.5.5.2 During test

.1 start of the ignition procedure
.2 start of the test (ignition)
.3 time when ventilating openings are closed
.4 time when the extinguishing system is activated
.5 time from end of agent discharge
.6 time when the fuel flow for the spray fire is shut off
.7 time when all fires are extinguished
.8 time of re-ignition, if any, during soak period
.9 time at end of soak period
.10 at the start of test initiate continuous monitoring as per 3.2.4

3.5.6 Tolerances

Unless otherwise stated, the following tolerances should apply:

| | | |
|---|---|---|
| .1 | length | ±2% of value |
| .2 | volume | ±5% of value |
| .3 | pressure | ±3% of value |
| .4 | temperature | ±5% of value |
| .5 | concentration | ±5% of value |

These tolerances are in accordance with ISO standard 6182/1, February 1994 edition [4].

**4 Classification criteria**

4.1 Class B fires must be extinguished within 30 seconds of the end of agent discharge. At the end of the soak period there should be no re-ignition upon opening the enclosure.

4.2 The fuel spray should be shut off 15 seconds after extinguishment. At the end of the soak time, the fuel spray should be restarted for 15 seconds prior to reopening the door and there should be no reignition.

4.3 At the end of the test fuel trays must contain sufficient fuel to cover the bottom of the tray.

4.4 Wood crib weight loss must be no more than 60%.

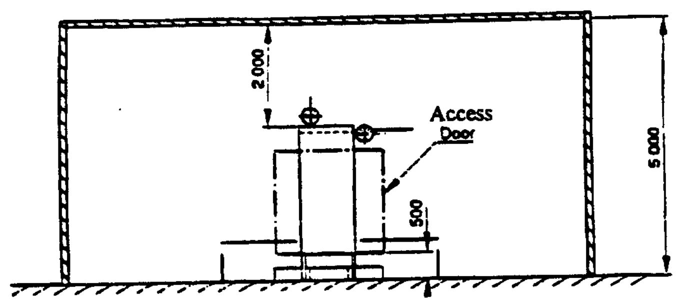
**5 Test report**

The test report should include the following information:

.1 name and address of the test laboratory
.2 date and identification number of the test report
.3 name and address of client
.4 purpose of the test
.5 method of sampling system components
.6 name and address of manufacturer or supplier of the product
.7 name or other identification marks of the product
.8 description of the tested product
- drawings
- descriptions
- assembly instructions
- specification of included materials
- detailed drawing of test set-up

.9 date of supply of the product
.10 date of test
.11 test method
.12 drawing of each test configuration
.13 Identification of the test equipment and used instruments
.14 conclusions
.15 deviations from the test method, if any
.16 test results including measurements and observations during and after the test; and
.17 date and signature.

Ceiling with ventilation hatches of minimum 6m²



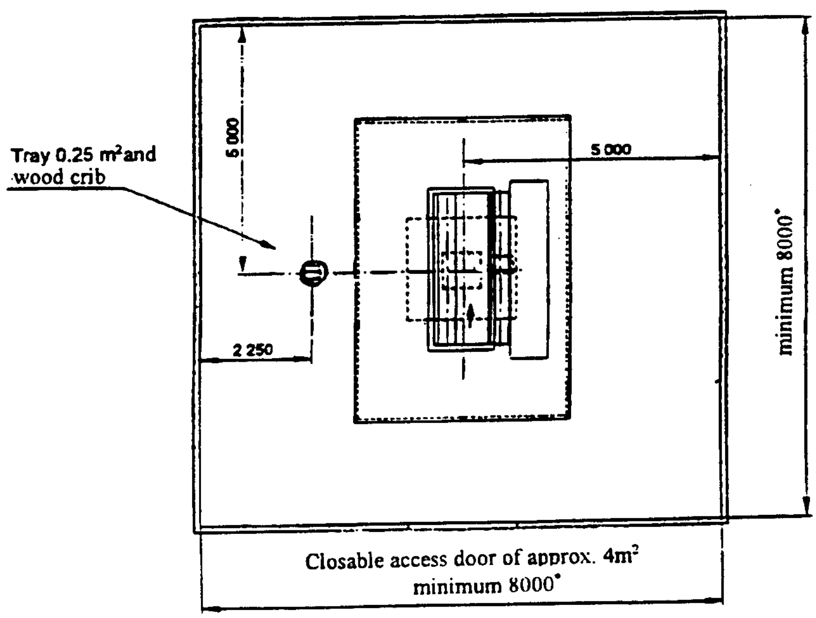




Figure 1

*The area should be 100m²

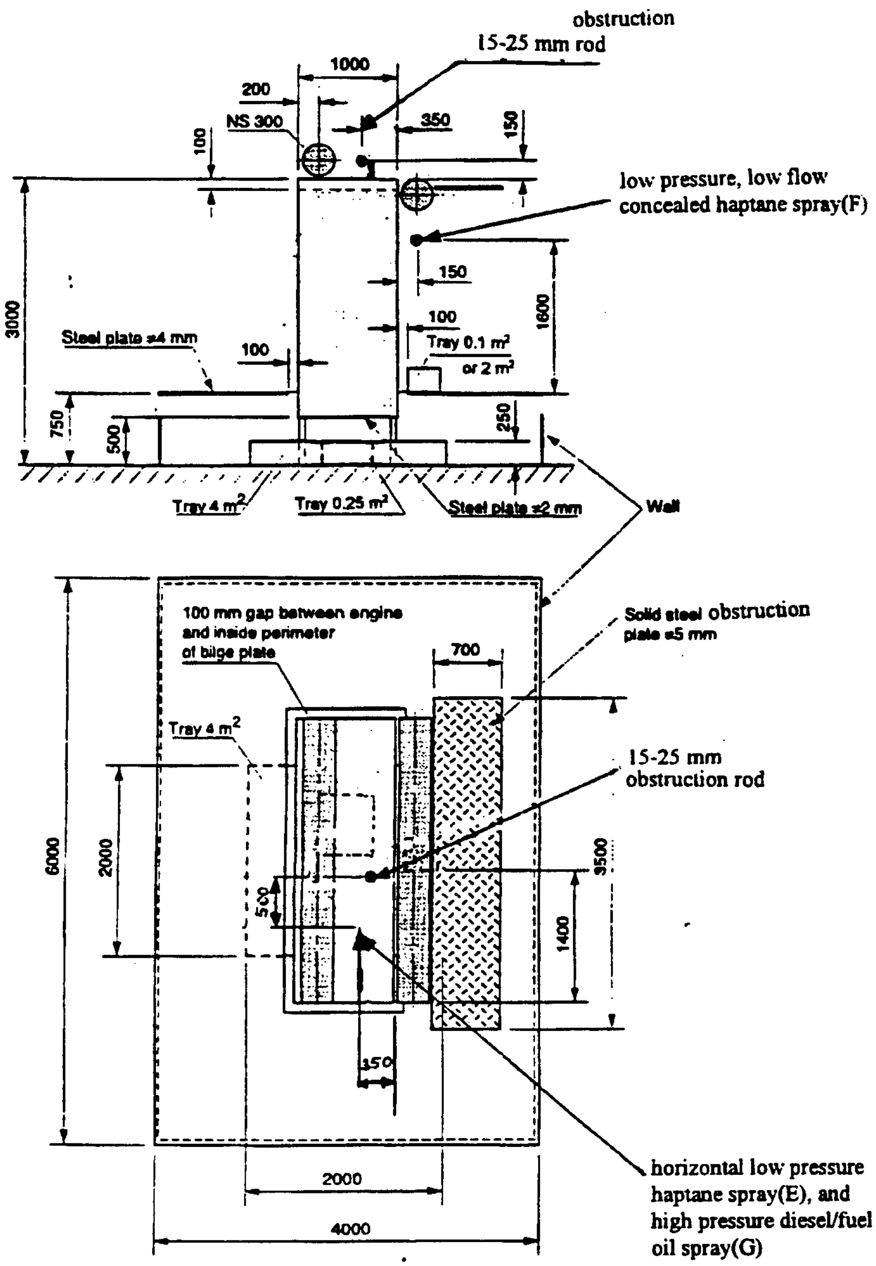

obstruction
15-25 mm rod
1000
200
NS 300
350
150
100
low pressure, low flow
concealed haptane spray(F)
150
3000
1600
100
Steel plate ≥4 mm
100
Tray 0.1 m²
or 2 m²
750
500
250
Tray 4 m²
Tray 0.25 m²
Steel plate ≥2 mm
Wall
100 mm gap between engine
and inside perimeter
of bilge plate
Solid steel obstruction
plate ≥5 mm
700
Tray 4 m²
15-25 mm
obstruction rod
6000
2000
500
3500
1400
150
horizontal low pressure
haptane spray(E), and
high pressure diesel/fuel
oil spray(G)
2000
4000

Figure 2

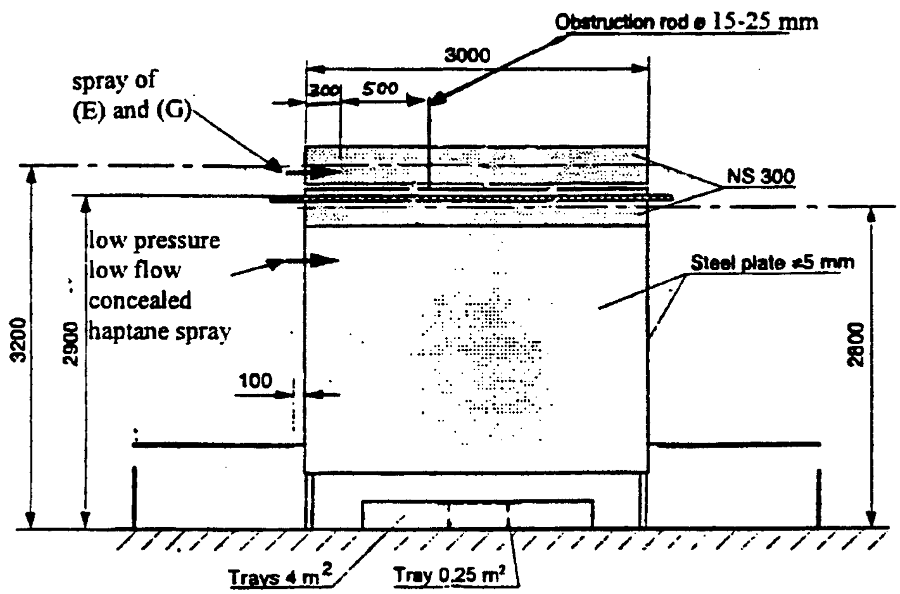

Obstruction rod ø 15-25 mm
3000
spray of
(E) and (G)
300
500
NS 300
low pressure
low flow
concealed
haptane spray
Steel plate ±5 mm
3200
2900
2800
100
Trays 4 m²
Tray 0.25 m²

Figure 3